The correlation between energy cost share, human and economic development: using time series data from Australasia, Europe, North America and the BRICS nations.

by

Ryan Keagan Roberts

Thesis presented in partial fulfilment of the requirements for the degree of Master of Philosophy in Sustainable Development in the Faculty of Economic and Management Sciences at Stellenbosch University

Supervisor: Prof. Josephine Kaviti Musango

Prof. Alan C. Brent

Dr. Matthew Heun

December 2017

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: December 2017

Abstract

Rising global temperatures and fossil fuel depletion have created urgency for a shift toward renewable energy. While the environmental benefits of this power source have been well documented, a blind eye cannot be turned on social and economic challenges facing many nations today. The overarching goal of this study is to investigate how a transition to an energy sector dominated by renewable energy systems would affect the other two pillars of sustainability, namely society and the economy. This is vital to understand in order to construct energy and environmental policies that can advance society in a sustainable manner.

One of the changes that would occur during such a transition is a variation in energy prices. The energy costs share (ECS), a ratio of a region's energy expenditure as a fraction of its gross domestic product (GDP), was identified a tool that could link the amount spent on energy in proportion to the size of a country's economy. Nations from three regions of the world, namely Australasia, Europe and North America, were chosen for this analysis. It was also decided to include the BRICS nations to give a representation of developing economies, giving a total of fifteen countries. During the period of 1978-2010, the annual energy cost share of each country was compared to the year on year GDP change at different time lags. The three components of a nation's HDI, namely income levels, health and education, were also compared to this metric. Pearson's Correlation test were conducted in order to establish the relationship between these indices as well as any thresholds that may exist. In an attempt to identify any common traits that may explain the dynamics of energy costs, comparisons between each country were made, along with similar tests performed for each region.

This study confirms that high energy costs have a negative effect on economic growth. The existence of an ECS threshold was found in many countries with very strong correlation coefficients being obtained for periods of high ECS. Throughout the study it was noticed that energy cost share had a very strong correlation to GNI per capita change, much stronger than the correlation between ECS and GDP change. The use of ECS may be good tool for stimulating economic growth, but more importantly it stimulates human development in the form of income levels. The findings from this study showed that each country has its own set of dynamics to energy cost share. Many influences can affect the dynamics of energy costs on

a countries economic and human development. The effects may be localised to a specific region, however, there are many other factors that can play a vital role such as a country's energy mix, economic situation and political history.

Opsomming

Al hoe hoër temperature wêreldwyd en die uitputting van fossielbrandstowwe vereis 'n dringende verskuiwing na hernubare energie. Hoewel daar al baie geskryf is oor die omgewingsvoordele van hierdie kragbron, kan 'n mens nie jou oë sluit vir die maatskaplike en ekonomiese uitdagings van baie nasies nie. Die oorhoofse doel van hierdie studie is om te ondersoek hoe 'n oorgang na 'n energiesektor wat deur hernubare-energiestelsels oorheers word, die ander twee pilare van volhoubaarheid, naamlik die samelewing en die ekonomie, sal raak. 'n Begrip hiervan is noodsaaklik om met energie- en omgewingsbeleide vorendag te kom wat volhoubare samelewingsvooruitgang kan bewerkstellig.

Een van die veranderinge wat gedurende so 'n oorgang sal plaasvind, is 'n wisseling in energiepryse. Die energiekosteaandeel, synde 'n verhouding van 'n streek se energiebesteding as 'n fraksie van sy bruto binnelandse produk, is geïdentifiseer as 'n instrument wat energiebesteding proporsioneel aan die grootte van 'n land se ekonomie kan koppel. Nasies uit drie wêreldstreke, naamlik Australasië, Europa en Noord-Amerika, is vir hierdie ontleding gekies. Boonop is die BRICS-nasies ingesluit as verteenwoordigers van ontwikkelende ekonomieë, wat die totale getal lande in die studie op 15 te staan bring. Die jaarlikse energiekosteaandee van elke land vir die tydperk 1978-2010 is met die jaar-tot-jaar-verandering in BBP met verskillende tussenposes vergelyk, sowel as met die drie komponente van 'n nasie se menslike ontwikkelingsindeks, naamlik inkomstevlakke, gesondheid en onderwys. Pearson se korrelasietoets is uitgevoer om die verwantskap tussen hierdie aanwysers sowel as enige moontlike drempelwaardes vas te stel. Om enige gemeenskaplike kenmerke te probeer bepaal wat die dinamiek van energiekoste kan verklaar, is vergelykings tussen elke land gedoen en soortgelyke toetse vir elke streek uitgevoer.

Die studie bevestig dat hoë energiekoste 'n negatiewe uitwerking op ekonomiese groei het. Heelwat lande blyk 'n energiekosteaandee-drempel te hê, met baie sterk korrelasiekoëffisiënte vir tydperke van hoë energiekosteaandee. Deur die hele studie is 'n baie sterk korrelasie tussen energiekosteaandee en verandering in bruto nasionale inkomste per kop opgemerk – veel sterker as die verband tussen energiekosteaandee en bruto binnelandse produk-verandering. Energiekosteaandee kan 'n doeltreffende instrument wees om ekonomiese groei te stimuleer. Nóg belangriker is egter dat dit menslike ontwikkeling in

die vorm van inkomstevlakke kan stimuleer. Die bevindinge van hierdie studie toon dat elke land sy eie stel energiekosteaandee-dinamiek het. Baie invloede kan ’n uitwerking hê op hoe energiekoste ’n land se ekonomiese en menslike ontwikkeling raak. Hoewel dit moontlik streekspesifiek kan wees, sluit hierdie invloede ’n land se energiemengsel, ekonomiese omstandighede en politieke geskiedenis in.

Acknowledgements

The journey that is a Master of Philosophy in Sustainable Development is not an easy one and I have no doubt in my mind that the support and assistance from the following people has guided me to my destination.

- To Prof. Josephine Kaviti Musango and Prof. Alan C. Brent. Thank you so much for the time and effort you gave in helping me complete this thesis. With your knowledge and experience I was able to put together a product that I am proud of!

- To Dr. Matthew Kuperis Heun, you have been instrumental in my journey. Thank you so much for always being willing to assist, I took comfort knowing your expertise was merely a Skype call away. I am extremely grateful for the kind-hearted manner in which you guided me over the last nine months.

- To Dr. Carey. W King, thank you so much for providing data that was essential to my analysis and this research.

- And certainly not least, to my family - Charmaine, Tyrone and Dean Roberts – thank you so much for supporting me throughout this journey. I could not have done it without you!

Table of Contents

List of Acronyms and Abbreviations

APF	Aggregate Production Functions
BRICS	Brazil, Russia, India, China and South Africa
CO_2	Carbon Dioxide
ECS	Energy Cost Share
EIA	Energy Information Administration
EROEI	Energy Return on Energy Investment
EROI	Energy Return on Investment
ERR	Energy Return Ratio
OECD	Organisation for Economic Co-operation and Development
GDP	Gross Domestic Product
GNI	Gross National Income
GW	Gigawatts
FDI	Foreign Direct Investment
HDI	Human Development Index
HDR	Human Development Report
IEA	International Energy Agency
IMF	International Monetary Fund
LEI	Lambert Energy Indicator
MROI	Monetary Return on Investment
NEPR	Net Energy Power Ratio
NGL	Natural Gas Liquid
NPR	Net Power Ratio
PPP	Purchase Power Parity
PV	Photovoltaic
TJ	Tera joule
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
US	United States

List of Figures

List of Tables

Chapter 1 – Introduction

1.1.Background

The world is in an energy crisis (Hartley, et al., 2016). It has begun to see the bottom of the once presumed inexhaustible pot of fossil fuels. Conventional oil, still running through the veins of our society, reached production peak in 2008 (IEA, 2008). Furthermore, global warming continues to race towards the 2°C, due to CO_2 emissions from fossil fuel consumption. Many first world countries have developed huge economies, heavily dependent on these fuels. Furthermore, third world nations with their large populations are desperately striving to be like Western Society.

The obvious solution to these challenges is to increase the contribution by renewable energy sources within a countries energy mix, with many nations identifying this. From 2004 to the end of 2014, global power capacity from renewable sources increased from 85 GW to 560 GW (excluding hydropower), more than 600% increase (REN21, 2014). In 2015, renewable energy sources accounted for more than half of installed power capacity (IEA, 2016). Yet renewable energy penetration is still some way off from being a major player, only accounting for 19% of the world's final energy consumption (REN21, 2014). Most of this new power generation occurs in a very small amount of countries. China, USA, India and Europe collectively account for more than 70% of the total renewable energy generated (REN21, 2014).

While the benefits of renewable energy have been identified, global adoption of these power sources is still a long way off. Nations of the world are also plagued with a plethora of, seemingly more urgent, problems such as poverty, inequality, poor education and so forth (UNDP, 2015). There are large amounts of evidence linking a transition away from fossil fuel power sources to environmental benefits, however, the on social and economic challenges facing many nations today cannot be neglected. Before making energy and environmental policies, it is vital to understand the dynamics of energy on economic and social development. A transition towards a green economy could have far-reaching implications on these elements and this information is crucial to ensure the change is done in a sustainable manner.

1.2. Rationale of the research

As the world faces an energy crisis, a transition to renewable energy is desperately needed in order to prevent resource depletion and climate change disasters. In order to achieve a sustainable society, however, the economic and social effects of such a change must be monitored. Understanding the dynamics between energy expenditure and the economy, as well as energy expenditure and human development, is essential to developing effective energy policies.

Previous research into this topic has identified an energy cost share threshold, above which economies are heavily dependent on energy expenditure (Aucott & Hall, 2014) (Bashmakov, 2007). These studies focus mainly on the US, OECD and global dynamics. King (2015) establishes the correlation between the economy and energy cost share for a one year lag for forty-four different nations, however the focus of the research is done for a global level. As most energy policies are constructed at a national or regional level, a deeper understanding of these dynamics must be gained. There is also a gap in the literature with regards to the relationship between energy expenditure and human development which was investigated in this study.

1.3. Research Problem Statement

The preliminary literature review indicates that existing studies provide an incomplete analysis on the dynamics between energy costs and the economy needed by policy makers to transition towards a clean energy strategy. Previous studies focus on global dynamics and the US economy, with limited analysis of other countries. Examining the dynamics of energy expenditure and the economy for other countries and regions, as well as the dynamics of energy costs and human development is essential in understanding the different correlations varying ECS has to different regions of the globe.

1.4. Research Objectives

In order to investigate the correlation between energy expenditure on the economy and human development at national and regional levels, the research had five sets of objectives. Fulfilling each objective relied on the completion of sub-objectives that are identified within each in the list below:

Research Objective 1: To investigate any existing literature relating to the correlation of energy cost share on the economy and human development at national and regional levels

Research Objective 2: To examine the relationship between energy cost share and economic growth for selected countries from different regions.

Research Objective 3: To examine the relationship between energy cost share and human development for selected countries from different regions.

Research Objective 4: To identify the correlation between energy cost share and economic growth; as well as energy costs and human development for selected countries from different regions.

Research Objective 5: Conduct a regional analysis of country data, in line with the methodology set out in Research Objectives 2-4.

1.5. Research Propositions

The literature analysed in Section 2 assisted in ascertaining research propositions for this study. By doing so, focus was put on determining whether or not these propositions hold true. These propositions are:

i. High energy cost share will have a negative correlation to economic growth. Studies into this field have occurred (Bashmakov, 2007; Aucott & Hall, 2014; King, 2015). This study wishes to extend this knowledge by increasing the amount of year lags this correlation is analysed as well unpacking possible reasons for the correlations that may occur.

ii. High energy cost share will have a negative correlation to human development. As no studies regarding this topic could be found, this proposition was established. The direction of the proposition was based on the first proposition and that economic and social development are related. Once again this study wished to explain any correlation between energy cost share and social development should it occur.

iii. The relationships between energy cost share and economic growth, and energy cost share and human development, differ from region to region. This proposition was based on the country analysis performed by King (2015). By grouping these countries into regions, it may be possible to ascertain that different ECS dynamics occur in different regions. Should this occur, the study wished to investigate possible reasons for this.

1.6. Limitations and assumptions of the study

Although this study intended to provide policy makers with information to construct energy policy, it purely focusses on the interactions between energy and the economy as well as energy and human development. Environmental considerations are not taken into account.

The study also does not consider the microeconomic and social effects of establishing the infrastructure for an energy transition, which is the creation or destruction of jobs in certain industries

1.7. Chapter Outline

Chapter 1: This introduces the study, highlights the rationale of the research, research objectives, scope of the study and provides a chapter outline.

Chapter 2: This chapter reviews current literature focussed on energy's effect on aspects of society. It takes note of the results and methodologies of existing studies and identifies gaps in the literature. A framework of how to address the problem was established.

Chapter 3: This chapter gives the methodologies chosen and steps taken in order to achieve the objectives of the study. The methodology used to research existing literature is also given in this section. Many of the methodologies chosen for this study are similar to previous studies in order to enable comparative analysis.

Chapter 4: The results of the analysis are provided in this chapter. An in-depth discussion of the results is provided according to the country, regional and "All Countries" analyses. Any similarities between the nations were highlighted.

Chapter 5: Provides findings of the study, limitations of the study and recommendations for further work into this field.

1.8. Summary

Currently, there is no study that can accurately provide a complete picture covering both social and economic interactions with energy. The hypothesis of this study is that ECS affect economic growth and human development and that these effects differ from region to region. The proposal that energy expenditure is correlated to the economy has been shown in previous studies; but little has been done on actual human development. The purpose of this study is to provide policy makers with more information regarding the understanding of how energy expenditures correlate with macroeconomic and social structures, assisting in the development of appropriate energy and environmental policies. Different regions of the globe need to be investigated, in an attempt to ascertain the different factors correlating energy and the economy as well as energy and societal development. In order to facilitate a sustainable transition towards renewable energy, these dynamics need to be understood.

Chapter 2 – Theory and Literature Analysis

2.1. Introduction

This chapter reviewed the current literature on energy's effect on aspects of society other than the environment. Sustainability is first defined in Section 2.1, which identifies the areas that need to be addressed. In Section 2.3 the social and economic effects of energy are then reviewed, with the different methods and variables to establish these links being covered. This then leads on to how energy metrics have been used to possibly connect the economy and energy within. Gaps in the literature were identified as well as approaches to fill these gaps. The chapter intends to identify how energy can affect economic and social structures as well as how it can be analysed.

2.2. Identifying Sustainability

In order to adjudicate whether or not a transition to a sustainable society could be facilitated, it was important to describe what sustainability meant and its defining characteristics. The publication of Our Common Future in 1987 (Brundtland, 1987) was the first real step toward towards a sustainable future, even though the description of this was very vague and could be interpreted in many ways. The term "sustainable development" was coined and has been the topic of discussion by many academics and beaurocrats alike. Due to the lack of clarity of the concept of 'sustainable development' provided by the Brundtland Commission, there have been many views of the term by many people, institutes, organisations etc. Mebratu (1998) reviews the many viewpoints that have been established over time and reveals how each of these views tends to favour the beliefs or goals of the specific parties. One thing that most of these parties agree on, even during the industrial revolution, is society needs to live in harmony with the environment (Mebratu, 1998). Hopwood et al. (2005) identify a common trend in most of these views. They state "*The usual model for sustainable development is of three separate but connected rings of environment, society and economy" (Hopwood, et al., 2005).* This coincides with the cosmic world model which suggests that the *"The ultimate objective of sustainability is the full integration of the natural, economic, and social systems, and this may be achieved through the integration of these objectives" (Mebratu, 1998).*

2.3. Socio-economic effects of Energy

Currently, mainstream economic thinking tends to neglect the importance of energy, chiefly because it is not identified as a primary factor of production such as labour and capital (Stern, 2011; Aucott & Hall, 2014; Heun, et al., 2017). The role of energy, more specifically energy consumption, as an essential driver of economic growth is identified by ecological economists (Stern, 2011). It is clear that there is not a consensus among economists of the role energy plays. These views are shared by Ozturk (2009) who made a survey of the recent progress in the literature of energy consumption–economic growth and electricity consumption–economic growth causality nexus. The findings showed conflicting results and there was no consensus on the existence of a link between energy consumption and gross domestic product (GDP) within the existing literature. Recommendations were made for scholars in the field to focus on new approaches. Heun, et al. (2017) used different methods to model the effects of energy in the economy by using aggregate production functions (APFs), commonly used by mainstream economists. Their findings revealed the lack of standard modelling approach, modelling evaluation and parameter precisions can lead to different interpretations of the economy and thus different energy policies. This confusion not only affects the development and quality of life for people worldwide, but is also occurring in the midst of environmental challenges such as climate change (Heun, et al., 2017). It is clear that this method of analysing the effects of energy in the economy still need a great deal of work, with the study proposing a significant list of future work. Another approach, using metrics other than energy consumption and APF’s, may be necessary at this stage.

Although GDP is a fairly plausible indicator of measuring economic growth on a regional, national or global scale, it fails to identify the quality and the distribution of said growth. There is the view that the world’s focus of increasing GDP is the main reason why many social inequalities are still experienced (Moore, 2015). Fioramonti (2013) points out many of the flaws of solely using GDP as a policy-making tool. The United Nations have used a different indicator, the Human Development Index (HDI), to measure human development in nations across the world. It gives an aggregated score between 0 and 1 for each country and takes into consideration mean and expected years of schooling, life expectancy as well as GNI per capita (PPP).

Although the weightings of each component as well as the exclusion of other indices are very subjective, it does provide a much better view of human development and is commonly accepted (UNDP, 2005).

Access to energy, more specifically electricity, has been identified as a key player poverty alleviation, with a large literature base (D'Amelio, et al., 2016; Kanagawa and Nakata, 2007; Lenz, et al., 2017; Nkomo, 2007). Nkomo (2007) found a strong link when analysing HDI levels and net energy consumption per capita using cross-sectional data from the SADC region. The use of this data could be one reason why these conclusions, differing from Ozturk (2009) were made. Kanagawa and Nakata (2007) show the links between energy access and human development components in Figure 2.1. Due to the modularity of renewable energy, it is possible to make a huge impact on areas where grid connection is not possible/feasible. However, these studies (e.g. D'Amelio, et al., 2016; Kanagawa and Nakata, 2007; Lenz, et al., 2017) focus purely on access to energy. If all the fuel sources currently being used were replaced with renewable ones (i.e. swap solar energy for coal energy, bioethanol for diesel), accessibility would still be a problem.

If a direct substitute were to be considered, assuming all the infrastructure remained the same, all the arguments against renewable energy (availability, efficiency, price etc.) would all come down to cost of energy. Therefore, analysing the change in cost of energy should give a better indication as to its effects on an economy and human development. This indicates why Ozturk (2010) found the lack of consensus in the literature on the link or direction of causality between energy consumption and economic growth, possibly due to fuel prices. These prices have a wide range of influences from technological innovation and demand to natural calamities and political circumstances. A different set of metrics other than APF’s and purely net energy consumption per capita need to be found.

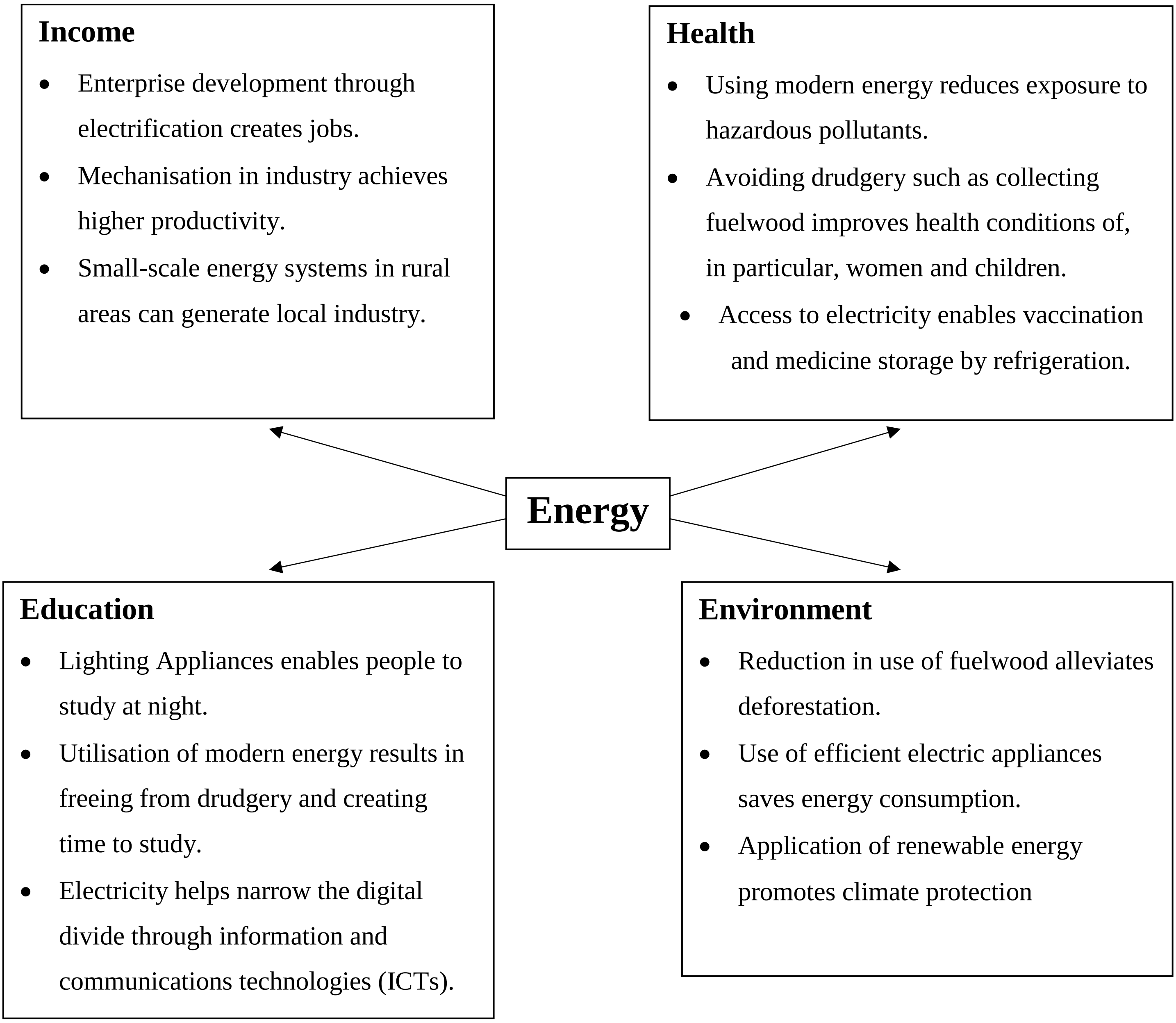

Figure 2.1.: Linkages between energy and human development

Source: Kanagawa & Nakata (2007)

2.4. Energy Metric Analysis

Studies using economic and biophysical metrics do exist, albeit on a smaller scale. Bashmakov (2007) proposed three laws of energy transition, the first of which provides great insight into the dynamics of energy cost and economic growth. It states that energy expenditure to GDP ratios, known as energy cost share, have remained relatively stable over decades and are very similar across regions and large countries. This index reflects the percentage of money spent on energy in order to generate wealth within an economy. The ECS of a particular country or region, x, can be calculated as follows:

$$ECS_x = \frac{Monetary\ Expenditure\ on\ Energy_x}{Gross\ Domestic\ Product_x} \quad (1)$$

Where Monetary Expenditure on Energy is the consumption of energy multiplied by its corresponding price. This formula provides us with the ratio of GDP that is spent on proving energy in a country for a particular time period. Furthermore, this first proposition states ECS to income ratios have also remained stable. Bashmakov (2007) posits that there is no correlation between energy costs, income levels and economic activity so long as a ratio threshold is not exceeded. Beyond this ratio threshold, economic growth becomes highly dependent on fuel expenditure and eventually slows down. This reduces energy demand, decreasing consumption and price, until the ratio is stable again. One hypothesis for this is that the increase in energy costs encourages consumers to become more efficient and reduce their consumption. The demand for fuel then slows which in turn drives down the price and the energy expenditure to GDP ratio. Once this threshold is reached, energy suppliers' revenues are limited by the rate of economic growth, thus a price increase by 1% leads do a reduction in demand by more than 1% (Bashmakov, 2007). The high prices make it favourable for accelerated energy production, further reducing demand and eventually the cost. An ECS threshold between 8-10% for the US and 9-11% for OECD countries was found by Basmakov (2007) using primary energy cost data. It also estimates an energy cost share threshold for final energy consumption to be much lower, around 4-5% for the US and 4.5-5.5% for the OECD. The study pinpoints energy cost shares to GDP growth and income proportions as important metrics to monitor. The energy cost share metric gives a good indication as to the position energy expenditure has in the economy at a particular point in time. Bashmakov (2007) provides some relationship between ECS and economic performance as well as a partial relation between ECS and human development, as a relationship between energy costs and income proportion. Bashmakov (2007) only provides a general threshold for OECD countries which not suitable enough for policy makers at a national or regional level.

Aucott & Hall (2014) further echoed the ideas of Bashmakov (2007) with regards to energy cost-economic growth nexus. If economic performance is solely analysed and energy expenditure is not a significant driver of economic performance, then low energy expenditures should be associated with slow economic development. This is so because, in theory, less economic activity would lead to less demand for products and ultimately a reduction in price. Conversely, if energy expenditures are related to economic development, then low economic performance should be characterised by an increase in energy expenditure (Aucott & Hall, 2014). Aucott & Hall (2014) also compared the energy cost share of the US to year on year change in GDP. The costs to obtain primary fuel sources (coal, oil, natural gas and nuclear ore) were used in calculating the energy cost share. Using statistical tests, a correlation between energy cost share and economic growth was found. Analysing a period from 1950-2013, the study suggested a fuel cost threshold was seen to be around 4%. Above this, weak economic performance is likely to occur. The problem with using expenditures on primary fuel to calculate energy cost share is that it cannot give an indication as to the price paid by consumers at the point of consumption. This omits the processing and transportation costs unique to each sources, which influence the final price paid by consumers. New methods of extracting energy are being explored and governments heavily subsidise specific energy markets. Making an assumption that variations in primary fuel costs will have an equal change in the final price paid by consumers does not consider the constant change occurring to these intermediary processes.

Aucott & Hall (2014) identify why the correlation between ECS and the economy is extremely important, namely that global oil production has peaked and that there is a declining energy return on investment (EROI) on existing energy sources. Hubbert (1956) initially estimated that peak oil production would occur around the year 2000 (see Figure 2.2)

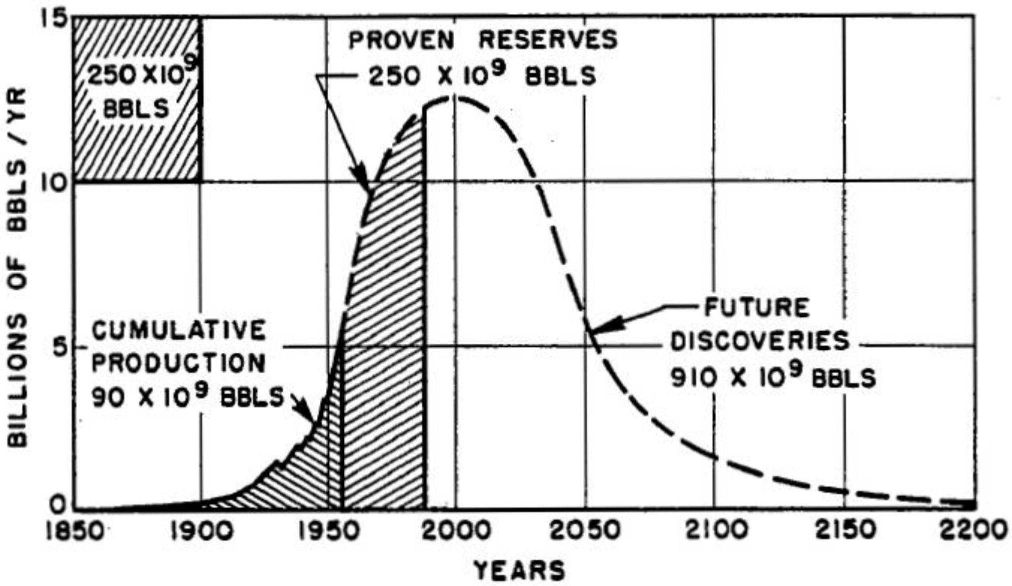

Figure 1.2: Global peak oil curve

Source: Hubbert (1956)

Murphy & Hall (2011) provide three points as to why global peak oil may, at the very least, be approaching soon. The first is that production is is outpacing new discoveries of oil. Secondly, during a 4-year period of high oil prices (2004-2008), production did not increase. And finally, most of the sources where oil is easy to extract have already been found and are being depleted. This final point leads on to another important ratio, energy return on investment (EROI) or energy return on energy investment (EROEI). This ratio is calculated as follows:

$$EROI = \frac{Energy\ extracted\ from\ source}{Energy\ invested\ into\ extraction} \tag{2}$$

Where the numerator is the total amount of energy available and the denominator is the amount of energy it takes for site exploration, source extraction, transportation and distribution. As oil continues to be depleted, there is a tendency for energy sources with smaller EROIs to be extracted. This is apparent as enhanced oil extraction techniques, such as nitrogen injection and deepwater oil wells are increasing (Murphy & Hall, 2011). These sources require more energy to supply fuel sources to society and ultimately increase the price of energy. Figures 2.3a and 2.3b below illustrate the scenario. Assume Source A and Source B have 100 units of energy to be extracted.

Even though the sources have the same amount of energy available, it would take five times as much energy to extract Source B as it does Source A due to the much lower EROI. Another way to examine the stituation is to estimate how many sources of similar size would be needed to produce a constant amount of energy. Lets assume society has a demand of 500 units of energy. It would take at least six energy sources with an EROI of 10 to fill this demand and provide a little extra, possibly for growth. Alternatively, it would take at least ten energy sources with an EROI of 10 just to satisfy the demand.

EROI = 10

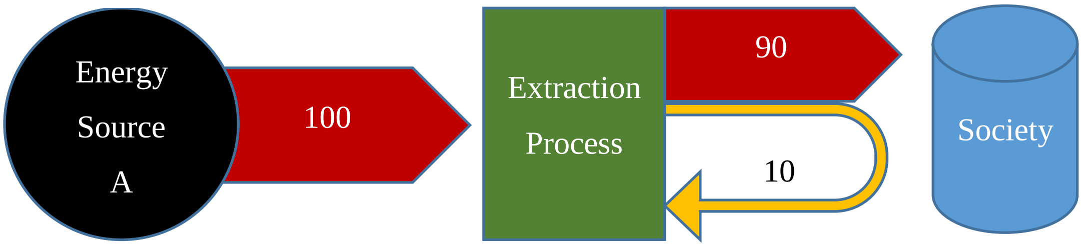

Figure 2.3a: Energy Source with EROI = 10

Source: Heun & de Wit (2011)

EROI = 2

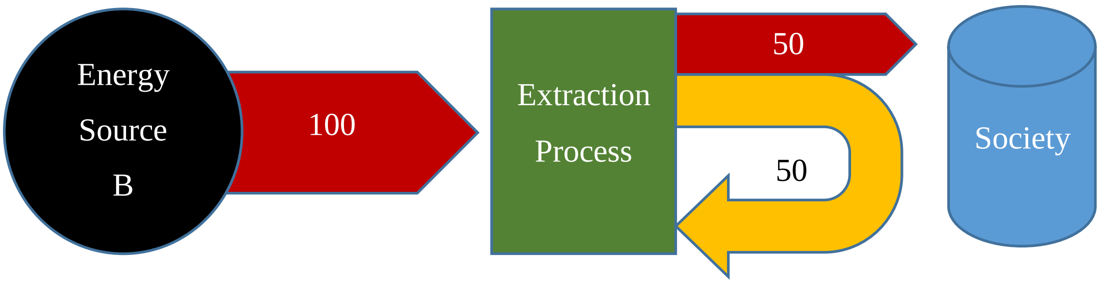

Figure 2.3b: Energy Source with EROI = 2

Source: Heun & de Wit (2011)

As a shift towards lower EROI energy sources continues it will be very difficult to maintain peak oil supplies as the discovery of new oil fields dwindle. The new sources not only need to match the demand, but also contend with the declining EROI. Murphy & Hall (2011) explain how a world consuming so much oil is in imminent danger by using the EROI energy metric. The study concludes by stating that global economic growth seen in the past 40 years will not continue in the long term unless a change in the economy is made. This necessary change could come if the following situations were to occur: a transition away from fossil fuels, especially oil as it accounts for an average of 45% of global fuel expenditures (King, et al., 2015), and redefining growth.

King & Hall (2011) derive equations in which one can link EROI, cost of energy and ultimately profits. The study established that as the EROI of an energy source decreased, the market price increased. Their argument is that this biophysical metric can be used as a tool by energy companies in deciding which energy technology to invest in. A statistical model developed by (Heun & de Wit, 2011) backs up these conclusions as the study links market prices and EROI in the following formula:

$$P_{E,t} = \frac{m_t \, c_{E,prod,t}}{1 - \left({}^{1}/_{EROI}\right)} \tag{3}$$

Where the average price of a particular energy source at a given period is $P_{E,t}$. The production cost of energy in the same period is given by $c_{E,prod,t}$ and m_t is the mark-up ratio of those production costs applied by energy producers. Although King & Hall (2011) look at using this metric from a business perspective, the same logic can be applied to national or regional energy policy. As marginal EROI energy supply often dictates the market price, energy sources with the greatest EROI should be used when deciding a nation's energy mix. This is no easy task as some fuels have differing uncertainty with regards to long term EROI. A coal-fired power station will have a greater uncertainty than a solar farm for example, due to the extraction processes of the coal. Murphy & Hall (2010) provided a diagram called "The Net Energy Cliff" and can be seen in Figure 2.4 below. The graph shows estimated EROI values for energy sources. It is worth noting that this was established using 2008 data and the positions of these energy technologies have changed. Due to factors established above, new oil and gas fields would most likely have slid further to the right. Improvements to renewable energy technologies would see solar PV and wind energy sources move more to the left. The most important point illustrated by this figure is that slight changes in EROI have little effect in the economy when these values are high (> ±10). But as these sources drop below this mark, the net energy gained from these sources decreases exponentially. If fossil fuel sources continue to dominate society's energy mix while their EROIs consistently drop, then the globe is moving toward a "net energy cliff", unless alternate sources can be found (Lambert, et al., 2014)

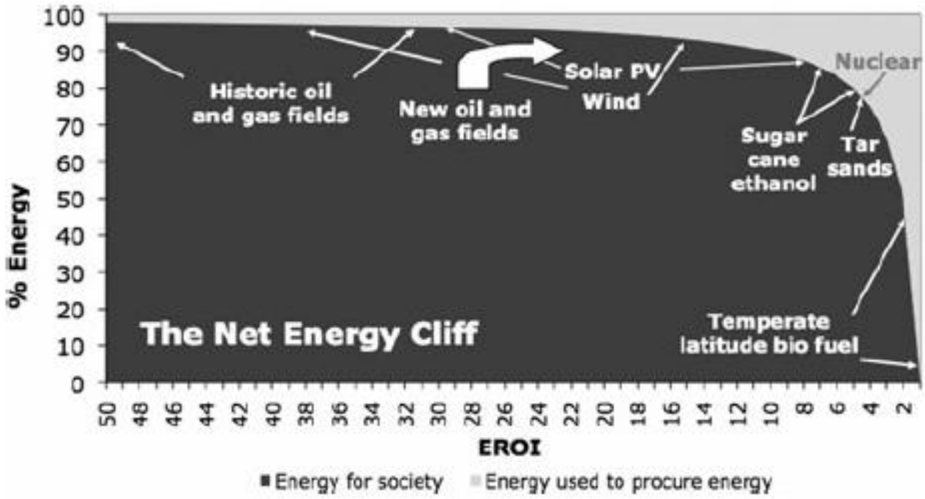

Figure 2.4: The Net Energy Cliff
Source: Murphy & Hall (2010)

The Net Energy Cliff alludes to the importance of using energy metrics as a policy-making tool. Long-term energy forecasting is currently done using projected production costs for various technologies. It is difficult to use costs as a measure as declining energy yields come into play. EROIs are a physical property of an energy source and is easier to predict over long time periods than prices (Dale, et al., 2011). For energy security purposes, nations need an energy mix. Once the technology specific EROIs have been calculated, policy makers could use this information for long-term planning in order to ensure affordable energy. More importantly, it is crucial to know the smallest possible overall EROI the energy mix can have in order for a society to continue to function.

The value of EROI extends beyond economic boundaries and into social well-being. Lambert, et al. (2014) compared the EROI of several nations to its HDI (Human Development Index) level and other social indicators. They showed that societies with an overall EROI higher than 15:1 tend to have HDI values of 0.7 and higher, which is considered highly developed. These results were similar when comparing EROI to other indicators such as the amount of children that are underweight, or people with access to clean water. Another indicator developed, the Lambert Energy Indicator

(LEI), is a combination of energy efficiency (EROI), energy use per capita and energy distribution (Gini coefficient is used as a proxy). This indicator showed a high correlation to HDI levels (R^2 = 0.84) and other social indicators. Lambert, et al. (2014) proposes that aid to developing nations will have little impact unless it targets improving the net energy per capita delivered to the country. As important as these findings are, it is difficult to analyse how the change in EROI or energy expenditure affects specific countries as the study used cross-sectional data (similar to Nkomo (2007)). Countries with high energy intensities will respond very differently to others with lower energy intensities if the price of fuels were to suddenly rise, as in the late 1970's. This article showed how energy metrics can influence social well-being, country specific time series data is needed to see the change in HDI can have.

Carey King, along with other authors, analyse the relationship between energy and economic metrics that is presented in a three part series. This is done as it is believed that net energy metrics are relevant to consider when constructing future energy policies. In Part 1, King, et al. (2015a) analyses how net energy and power metrics can be related to economic metrics. The study makes an interesting finding in that technology specific energy return ratios (ERR) are linked with energy costs while power return ratios (PRR), the derivative of ERR over time or the instantaneous ERR, is linked to energy prices. These metrics can, therefore, be used to calculate energy expenditures, further alluding to their importance when planning a regional energy mix.

In Part 2 of the series, King, et al (2015b) analyses the worldwide monetary expenditures on energy from 1978-2010. The energy cost share is used as an economic metric for this analysis, using consumption and price data from 44 different countries which contribute over 90% of global GDP. The study also analyses a PRR over this same time period, the net external power ratio (NEPR) which can be calculated as follows:

$$NEPR = \frac{Annual\ Energy\ Production - Annual\ Energy\ Industry\ Consumption}{Annual\ Energy\ Industry\ Consumption} \qquad (4)$$

The annual energy industry consumption is comprised of all the fuel used by energy producers for operations, extraction, distribution etc. Another economic metric is introduced, the net power ratio (NPR) which is the inverse of energy cost share. In theory, the NEPR should always be high than the NPR. It was found that when these two metrics are nearly equal, low world growth occurred. This study goes someway into finding a tool in which a threshold in energy expenditure can be found and concludes that the most practical metric of EROI may be the NPR.

The final part of the series, King (2015) provided a general correlation analysis between energy cost share and economic growth. Point of consumption prices for different fuels such natural gas, coal, petroleum and electricity were used to calculate energy cost share and it was also compared to the year on year change in economic growth. As the final price is what is experienced by the economy, it is reasonably robust to assume to that these prices will affect economic growth (King, 2015). The same argument can be made for human development. Using data from 1978-2010 and forty-four countries as a representation of the globe, the results showed a statistically significant negative correlation to energy cost share and a one year lag in gross domestic product. This indicates that costs of energy are an important factor in global economic growth. The Pearson's Correlation Coefficient calculated in King (2015) for each country showed the sensitivity energy cost share has on each country, however, it is clear that most of the correlation coefficients established were not statistically significant. This may be partially due to the lack of accurate time series data available. The International Energy Agency (IEA) has a significantly rich database of energy consumption and prices; however there are large amounts of gaps. King (2015) provided a more than suitable methodology in order to estimate this data. It is important to note that this data series is only thirty-two years, which may seem like a long enough period. But with assumptions of data that need to be made that can increase the spread of data, a significant correlation can be difficult to prove. Secondly, and more importantly, this study gives a general overview of the correlation over the time. Bashmakov (2007) revealed that energy prices play little role in influencing economic growth in general terms. It is only when energy expenditure reaches an upper threshold, that it restrains the factors contributing to economic growth such as labour and capital. If this theory holds, critical energy cost shares, identified by Bashmakov (2007) and Aucott and Hall (2014) are perhaps more important than general correlation coefficients.

Consideration must be given to the fact that these thresholds may be different from country to country, depending on whether it is a net importer or exporter of energy, and quite possibly could change with time. More so, energy policies are generally made on a national/regional level and not on a worldwide scale. Establishing these thresholds, if any, and determining a correlation between economic growth and critical energy expenditures once these thresholds have been exceeded is of utmost importance. These thresholds can then be linked to energy metrics, such as EROI, in order to plan an energy mix.

Fizaine and Court (2016) conducted a similar study where they estimate energy cost shares for the US and the world economies from 1850 – 2012. The authors recognise the importance of including biomass in energy expenditures and make an attempt at including this fuel source. More than 2.7 billion people are estimated to rely on fossil fuels for energy sources, most of these coming from developing Asia and sub-Saharan Africa (IEA, 2016). The use of this energy contributes heavily to global warming, deforestation and respiratory illness levels (IEA, 2016). If a transition away from CO_2 based energy sources towards cleaner fuels is to be achieved, it is vital to take into account biomass. The study goes one step further than the correlation test performed by King (2015) and uses performs Granger causality tests for different variables of the US economy such as oil expenditure, GDP growth, unemployment rate and capital formation. The results showed there is a statistically significant negative Granger causality from oil expenditure (oil cost share) to US GDP growth from 1960-2010. This is an important finding as previous correlation studies only idnetify a relationship between ECS and economic growth. This on the other hand proves that high expenditure on oil causes low growth in the US. A similar negative causality was found for total energy expenditure and US GDP growth, however, the limited amount of data points could not produce statistically significant results. Once again the scarce availability of data points limits the potential findings of the study.

The study postulates an ECS threshold of 11% for the US using Energy Information Administration (EIA) data and links this to a minimum societal energy return on investment of 11:1. The EROI is linked to this threshold using the following formula:

$$EROI = \frac{MROI}{Threshold} \tag{5}$$

Where Monetary Return on Investment (MROI) is the economic metric of the EROI:

$$MROI = \frac{Revenue\ extracetd\ from\ source}{Money\ invested\ into\ source} \tag{6}$$

This MROI is the total MROI for a society, including all its energy sources. Fizaine and Court (2016) gives the most detailed understanding between energy expenditure and economic growth needed by policy makers. They made coarse assumptions in establishing worldwide expenditures (by using prices from the US). This is understandable as little data is available regarding country-specific costs. The energy market has evolved drastically over the last 60 years and using a time series dating back to 1850 is unnecessary. The calculation of an overall minimum EROI is an important energy metric, showing an inverse relationship to energy cost (King & Hall, 2011), (Heun & de Wit, 2012). Using EROI as a policy-making tool can allow decision makers to invest in energy resources that will promote economic growth. Fizaine and Court (2016) alludes to the idea of comparing energy cost share to GDP per capita instead of total GDP. Such analyses would provide a better idea of human development in a country.

Arshad et al (2015) developed a macroeconomic model to examine the impact of energy prices on economic growth in Pakistan. They showed that an increase in energy prices negatively affects stock prices, inflation and productivity of the country. This affects real wage rate and government spending, leading to more unemployment. Although they make no mention of possible energy expenditure thresholds and minimum EROI values, there is evidence that energy cost share affects societal and economic growth. Murphy & Hall (2011) suggest that “when energy prices increase, expenditures are re-allocated from areas that had previously added to GDP.” This may also apply to social structures that indirectly affect economic growth and is worth investigating. Although access to energy plays a key role in alleviating poverty (D'Amelio, et al., 2016; Kanagawa and Nakata, 2007; Lenz, et al., 2017; Nkomo, 2007), it was unrecognized as a factor of poverty, being excluded in Millennium Development Goals. This could explain why an enormous gap in the literature regarding energy costs and human development exists, making it more difficult for policy makers to develop energy plans that benefit society.

2.5. Conclusion

While the links between energy and the environment have been well documented, this study investigated its effects on society and the economy. From the literature reviewed it was established that mainstream economists disregard energy to constitute a major part in economic growth, similar to labour and capital (Aucott & Hall, 2014, Heun, 2016, Stern, 2011). This is partly due to the fact that energy expendiyure generally makes up to around 5% of GDP (Aucott & Hall, 2014). Mainstream economists fail to consider the possibilities cheap energy can make on society as well as the extreme dependence modern day society has on energy. Previous literature that has compared energy consumption to economic growth show that the causality between energy and economic growth is ill-defined. Energy metrics such as EROI and energy cost shares show a much stronger link between energy and the economy (Arshad, et al., 2015); (Aucott & Hall, 2014); (King, 2015). If a smooth transition towards clean energy technologies is the end goal, this relationship is even more important, as studies have shown that renewable energy development is more likely to occur in countries that have stable growth of around 4% (Chang, Huang, & Lee, 2009); (Gan & Smith, 2011). These studies provide valuable information, but fail to provide a complete picture of the dynamics between energy and the economy needed by policymakers to transition towards a clean energy strategy. There is also very little literature comparing energy metrics to human development.

Chapter 3 – Research Methodology

3.1. Introduction

This chapter discusses the methodologies that were chosen and steps taken in order to achieve the objectives of the study. The methodology used to research existing literature is also given in this section. The research methodology involved using secondary ECS, GDP, GNI per capita and HDI data. ECS was then compared to a country's or region's GDP, GNI per capita or HDI indices for the time series being analysed. The strength of any correlations between ECS and the economic and social indices were then calculated using Pearson Correlation tests. This methodology was chosen as it is similar to previous studies and gives comparable results. Due to the lack of data, a fair amount of assumptions had to be made. The approach to these assumptions, also similar to previous studies, is shown here with the complete list of the studies shown in Appendix A. It is important to note that the completion of Objective 1 was essential for the completion of the other objectives. Completion of the sub objectives 2.1-2.4 was very much an iterative process due to the lack of data availability. This is explained in depth in Chapter 3. In order to accurately complete Objective 3, the data gathered in sub-objective 2.4 was used.

3.2. Research Objective 1: To investigate any existing literature relating to the dynamics of energy costs on the economy and human development at national and regional levels.

The first objective aimed at reviewing the literature that relates to the dynamics of energy cost on economy and human development in order to ascertain any relationships that had previously been established. The process to achieve this objective is discussed in the section that follows.

3.2.1. Literature Analysis

In order to obtain any information on the effect of energy on economies and human development, the "building blocks" search technique was used. This involved breaking down the topic into three subjects and searching for these using a specific database. The subjects were energy, economic and social growth, and regions. Similar phrases for each subject were also used in a wide variety of combinations, ensuring a large literature base was search. Table 3.1 below shows the combinations of keywords used for the search. The databases chosen for the search were EBSCO host and Scopus. The following databases were selected for the search when using EBSCO host: Academic Search Premier, Business Source Premier, EconLit and Greenfile. Once relevant literature was obtained, the "pearl growing" search technique was used in order to obtain other relevant sources of information. This helped tremendously in finding other relevant studies that were cited in the studies that had been analysed. The search for existing studies was an iterative process with subjects not originally considered fed back into the building blocks search.

Table 3.1: Table showing search terms for building block search

Energy	Economic and Social Change	Region
Energy	Economic growth	National
Energy price	GDP	OECD
Energy expenditure	GDP per capita	North America
Energy cost share	Growth	South America
Fuel	Human Development	Africa
Fuel cost	Economy	Asia
Fuel price	GNI per capita	Europe
Fuel expenditure	HDI	World
Power cost	Sustainable development	Country
Power price	Sustainability	Continent
Energy metrics	Society	BRICS
Energy	Economy	Regional

3.3. Research Objective 2: To examine the relationship between energy costs and economic growth for selected countries from different regions.

The next objective involved analysing the effect of energy costs on economy. In order to establish a relationship for different regions, the following objective was broken down into the following sub-objectives:

- Sub Objective 2.1: Establish energy cost metric
- Sub Objective 2.2: Establish economic metric
- Sub Objective 2.3: Select regions and countries within

- Sub Objective 2.4: Gather data for each country

The completion of these sub-objectives is described in the follow section.

3.3.1. Identifying an energy metric

From the literature it was obtained that energy cost share was a more appropriate metric to measure the effects of energy. Keeping in line with the current literature, the energy cost share of each nation would be used. This metric not only takes into account the energy expenditure of a nation but also the size of its economy. Three types of energy expenditures could be calculated, namely primary, intermediate or final expenditure. Primary expenditure involved using the price and consumption data of the raw fuels (eg. oil, coal) and would make the assumption that any increases in price of these primary fuel sources would be directly proportional to the price paid to the consumer. Intermediate expenditure relates to the cost to produce the energy source, excluding transport costs to the consumer. Final energy expenditure would involve using consumption and price data experienced by the consumer. It was decided that this form of energy expenditure, although dependant on data availability, would be ideal to use as discussed in the literature analysis. As the final price is what is experienced by the economy, it is reasonably robust to assume to that these prices will affect economic growth (King, 2015) and human development.

3.3.2. Identifying an economic metric

The most commonly used metric to measure economic growth is the change in gross domestic product. Even though this method has its flaws, discussed in Section 2.4 of literature review, much of the current literature uses this metric. In order to allow for comparative analysis, this study utilised gross domestic product as an economic metric.

3.3.3. Country selection for investigation

The choice of nations to be analysed was largely dependent on the need to undertake comparative analysis between regions and countries from different continents well as data availability. The five largest countries, economically, were chosen to represent

Europe. Due to data limitations for Africa, Asia and South America, the BRICS nations that are seen as upcoming economic players were included as a representation of the 'Global South'. The use of these nations obviously gives a very poor representation of the nations in their respective continents as they are the economic leaders. However, the choice was influenced by data availability. The countries selected from each region for the investigation are shown in Table 3.2 below.

Table 3.2.: Table indicating the selection of countries by region used for the analyses

Australasia	Europe	North America	Global South
Australia	France	Canada	Brazil
New Zealand	Germany	Mexico	China
	Italy	United States	India
	Spain		Russia
	United Kingdom		South Africa

3.3.4. Data needed for each country

In order to calculate the energy expenditure data, the energy source consumption of each country along with the corresponding price is needed. This is then divided a country's GDP for each year of the time series being analysed. GDP and HDI data is then needed to compare how ECS affects economic and social growth. This sub-section explains how this data was obtained.

3.3.4.1. Energy expenditure data

An analysis of the literature found as well as an internet search was used in an attempt to obtain information regarding energy price and consumption data for each country. It was seen that the IEA database provided the most comprehensive price and consumption data of energy sources for different nations from 1978-2010. It also provided final energy price and consumption data, which was preferred for the study. The database provides national price and quantity data for three sectors (industrial, electricity and residential) for natural gas and coal (separated into 5 coal types), two sectors (industrial and residential) for electricity and oil (separated into eight products in total) the annual average price for the fuel is given and monthly weightings are not considered. Even though this was the most comprehensive database of energy data, there was still large amounts of price and quantity data missing, especially from third world countries. The IEA database was used by King, et al. (2015b). After an analysis of the methodology used to account for the missing data points, it was decided to use the energy cost share data published by King, et al. (2015b) for this study. The use of different data sources and different methodologies with large assumptions would produce results with a large amount of estimated error. As in the case from the literature studied there were multiple thresholds for enegry cost share calculated for the US as there were different methodologies used for each. Using ECS data generated would give comparable results as well as allow country and regional comparisons.

3.3.4.2. Consumption data estimation

Energy consumption data for each fuel type was calculated as follows:

Oil energy consumption: mass of consumption multiplied by the net calorific value (e.g., kJ/kg).This was done for:

- crude oil;
- natural gas liquids (NGLs);
- refinery feedstocks;
- additives/blending components; and
- other hydrocarbons.

Natural gas energy consumption: was obtained from the IEA (in TJ) for

- electricity;
- industrial and
- residential setors.

Coal energy consumption: mass of consumption multiplied
by the net calorific value (e.g., kJ/kt). This wass done for the following products:

- anthracite;
- coking coal;
- other bituminous coal;
- sub-bituminous coal; and
- lignite, in

- electricity;
- industrial and
- residential sectors.

Other non-fossil fuel electricity generation sources are also given for the following:

- nuclear;
- hydropower (including pumped hydro storage);
- solar (two sub-types);
- tide, wave and ocean and
- wind.

3.3.5. Price data

As explained in the supplementary documents of King, et al. (2015b), the information needed to calculate national energy expenditure, is usually limited by price data. The hierarchy used to allocate prices to missing data points is as follows:

1. Use other in-country prices for different sector product for given year
2. Use nearest geographic neighbour price for same product
3. Use nearest geographic neighbour for similar product
4. Use global average price based on available prices for that year within that sector. Minimum dataset points given to resource producing nation

(The price allocations used for this study are given in the tables found in Appendix A.)

3.3.6. GDP Data

The annual change in GDP growth for each of the nations from 1978-2015 was obtained from the World Bank database (http://databank.worldbank.org/data). The GDP data for Russia pre-1991 was obtained from the OECD database (http://www.oecd-ilibrary.org.ez.sun.ac.za/statistics).

3.4. Research Objective 3: To examine the relationship between energy costs and human development for selected countries from different regions.

In order to examine the relationship between energy and human development, Research Objective 3 was split into the following sub-objectives:

- Sub Objective 3.1: Establish human development metric
- Sub Objective 3.2: Gather data for each country

This section explains how these sub-objectives were completed.

3.4.1. Human Development Metric

Since there is limited literature on the effects of ECS and human development, an appropriate measure was required. As a starting point the human development index was identified as a possible indicator for human development as it is widely used by policy makers (Ravallion, 2010). This index constitutes three key indicators of human development, namely a long and healthy life, access to knowledge and a decent standard of living. The HDI is the mean of these three indicators. A graphical representation can be seen in Figure 3.1 below. Minimum and maximum values for each indicator are set and an index between 0 and 1 is calculated (See Table 3.2). The setting of these "goalposts" are based on historical evidence and previous studies.

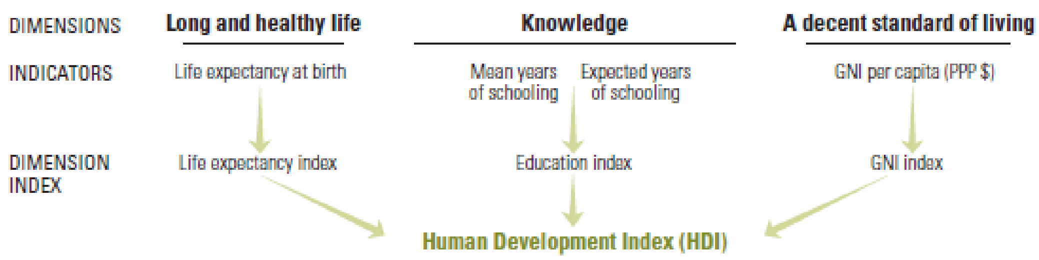

Figure 3.1: Figure showing the calculation steps of the Human Development Index

Source: UNDP (2015)

Table 3.3: Table indicating boundaries used to calculate the components of the HDI

Dimension	Indicator	Minimum	Maximum
Health	Life Expectancy (years)	20	85
Education	Expected years of schooling (years)	0	18
	Mean years of schooling (years)	0	15
Standard of living	Gross national income per capita (2011 PPP $)	100	75 000

Source: UNDP (2015)

The HDI has received criticism due to its data use, very "westernised" view of development and classification system (Wolff, et al., 2011). It is argued that the human development index fails to take into consideration any environmental impacts, as countries with high HDI values have a high ecological footprint (Moran, et al., 2008), and should not be fully used as a policy indicator. The study conducted here, however, makes the assumption that a large scale shift towards renewable energy will benefit the environment and the purpose is to analyse whether this transition will have an effect on the economy and society. Ravallion (2010) argues that the aggregating the three indicators fails to identify problems in each dimension. For example, a country with a falling life expectancy due to a bad health care system could still increase its annual HDI value with a good rate of economic growth. Therefore, this study analysed the effects of energy cost share on each indicator rather than look at an HDI value as a whole. The latests methodology used to calculate HDI, established in 2010, will be used for all the nations. The updated version uses new dimensions as explained in Figure 3.1 ad Table 3.2 above.

Identifying the three components of human development, indicators representing health, education and standard of living needed to be chosen. There are many health statistics that have been measured, providing data that can monitor the state of health in a specified area. Knowing that the energy cost share of a nation could have rapid growth and decline, a health indicator able to react to these sudden changes would be ideal. When analysing the databases (IMF, Worldbank, UNESCO, UNDP etc.) it was clear that data availability would limit the choice of indicator as many countries have incomplete stats going back to 1980. In the end, it was decided to use the health index used to calculate the HDI as seen above in Figure 3.1. Life expectancy stats were fully complete for all countries and there were no assumptions for missing data.

The same logic of indicator choice was applied to the education element, one that could be flexible to the rapid changes in energy expenditure. Many indicators were once again considered. Identifying a suitable indicator was limitted by data availability as a data was needed for all the countries for the time series chosen. The education index used in the HDI was chosen following the same method.

Identifying a standard of living index was easier as there are more complete datasets for each country. The GNI per capita value used in the HDI was chosen. This indicator is very flexible and would keep in line with the ideology of the HDI. The GNI per capita would however be analysed as an annual percentage change and not as an HDI index, ie. the year-on-year change of GNI per capita statistic would be used. As another economic indicator, the annual change in GDP, will also be used in the study it was decided to keep the units of these two indicators the same in order to compare them. As the GNI per capita for all the countries being analyzed sits comfortably between the limits used to calculate the HDI, an annual change would still provide an accurate component of human development.

3.4.2. HDI Data

The annual change in GNI per capita change for each of the nations from 1978-2015 was obtained from the World Bank database (http://databank.worldbank.org/data). The annual change in GDP per capita growth was allocated in the event of missing data points. This applied in the following circumstances:

China: 1978-1990;

New Zealand: 1978-1998; and

Russia: 1978 - 1990

The data required to calculate the life expectancy index, namely life expectancy at birth, were extracted from the World Bank database (http://databank.worldbank.org/data). The data required for the education index, represented by the mean and the expected years of schooling, was obtained from the United Nations Development Programme website (http://hdr.undp.org/en/content/expected-years-schooling-children-years). Values for mean and expected years of schooling are only monitored every 5th year from 1980-2005, afterward this is captured every year. Proportional interpolations were used to fill in the missing data points from 1980-2005, showing the trend of the education index of that time period. This calculated the value for each year based on the change between the points collected every five years.

3.5. Research Objective 4: To identify the correlation between energy costs and economic growth; as well as energy costs and human development for selected countries from different regions.

Once the data was obtained for the countries, a suitable method to establish any relationships was needed. Each nation was analysed using the following three step process:

i. Graphs comparing the energy cost shares to economic and human indicators were designed. From these, an understanding of how each indicator trends in relation to a change in energy expenditure was obtained. Any patterns or thresholds were identified.

ii. Overall Pearson correlations for the entire time series were established tp confirm whether or not there is a relation. As there could also be a lag of up to three years in any effects (Fizaine & Court, 2016), four correlation coefficients was be calculated along with their corresponding *P*-values.

iii. As energy expenditure has a noticable effect on the economy once a certain threshold has been exceeded (Bashmakov, 2007), correlation coefficients were found over periods of time where the energy cost share threshold established in (i) was calculated. This was done for the metrics where a correlation was identified.

It is important to quantify any relationships seen in the results once they have been processed. King (2015) uses a Pearson's Correlation test to identify any patterns seen in the data. This test measures the relationship between two data sets and provides a correlation coefficient, between 1 and -1, indicating the nature of the correlation. A coefficient of 1 gives a perfect positive relationship while a value of -1 gives a perfect negative correlation. In order to establish whether or not the correlation found is statistically significant, the *P*-value for each correlation coefficient will also be calculated. The *P*-value indicates the probability of establishing future results from past data if there was no correlation. The null hypothesis H_0 for this test is set at $r = 0$ and the alternate hypothesis H_1 is $r \neq 1$. The *P*-value is dependant on two factors, the strength of the correlation of the existing data as well as the sample size of the data set. From literature it was established that the dataset may be limited, a significance level of 10% was chosen for this study. Thus a *P*-value < 0.1 will ensure the null hypothesis is not rejected and the correlation is statistically significant. It was decided to use this same method as King (2015) in order to produce comparable results. A commonly used statistical analysis software package R was used to calculate these correlation coefficients.

3.6. Research Objective 5: Conduct a regional analysis of country data, in line with the methodology set out in Research Objectives 2-4.

The procedure described in Section 3.5 was applied to the regions from which each country originated. Although strictly not a region, the BRICS nations were treated as a representation of fast developing third world nations. In order to perform a regional comparative analysis the total energy cost share, GDP growth and GNI per capita values for the four regions (North America, Europe, Australasia, BRICS nations) were calculated.

The regional GDP change was calculated in the following steps.

i. Obtaining annual GDP for each nation
ii. Summing GDP figures to obtain a regional GDP for each year
iii. Calculating the year on year change of GDP from the region

The regional energy cost share was calculated in the following steps.

i. Converting the GDP data obtained from US$2010 to US$2005, the price deflator in Appendix D of Annual Energy review of 2011 by the EIA, see (EIA, 2011), was used for the conversion. This was done as the GDP data used to calculate the energy cost shares was done in US$2005.
ii. Multiplying GDP figures in (i) by the energy cost share figures, which resulted in an annual energy expenditure for each country.
iii. The annual energy expenditure was then summed for each country with the region over the time series.
iv. This total annual energy expenditure was then divided by the regional GDP for each year, resulting in a regional energy cost share.

The regional GNI per capita change was calculated using the following steps:

i. Obtaining annual GNI for each nation
ii. Summing these GNI figures to obtain a regional GNI for each year
iii. Obtaining the annual population for each nation
iv. Summing these population figures to obtain a regional population for each year
v. Dividing the GNI value with its corresponding population figure to obtain a regional GNI per capita change.

3.7. Summary

A thorough literature analysis was done using the two search techniques. Existing literature was studying, taking into the account the objectives and methodologies of previous studies. These studies, as well as an in-depth internet search, showed that data availability would be a limiting factor to the research and assumptions and compromises would have to be made. This factor influenced the country selection of the analysis. Indicators reflecting the economy and human development were chosen on the basis that they are widely used policy-making tools, however data availability played a role in the selection process. A stepwise data analysis strategy was taking into account the objectives of the study as well as the given data. In the end, a research was designed to produce comparable results to existing literature. It was evident throughout that data availability limited the study and an iterative process between research method and data collection had to be adopted. A collection of quality data is essential for policy makers and a greater effort is needed to record statistics of the past and present in order to plan for the future.

Chapter 4 – Results and Discussion

4.1. Introduction

This chapter presents the results of the investigations into the different countries and regions selected. The dynamics of energy cost share on the nations was first analysed by plotting the ECS against the selected economic and human development indicators. Should any patterns be identified, a correlation test between ECS and the metrics was conducted. Statistically significant results, those having *P*-values less than 0.1, are displayed in bold. After this, the correlation test was conducted for periods of high ECS in order to establish any possible ECS thresholds. In a similar fashion, the statistically significant correlations are displayed in bold. The strongest correlation found was published for the ECS threshold test, with the time lag used to establish the correlation given in brackets. The estimated ECS threshold, the highest ECS value of the time period, was also given.

Section 4.2 provides an analysis of the countries chosen. This is then followed by Section 4.3, a regional analysis of North America, Europe, the BRICS nations and Australasia. An 'All Countries' investigation then follows in Section 4.4, in order to provide insight into global energy cost dynamics. Discussions about the results are provided throughout the chapter. These consider comparing the dynamics of different countries. The groupings of these nations are discussed in Section 4.5, followed by a summary of the results in Section 4.6.

4.2. Country Analyses

The data obtained for each country was subjected to the analyses procedure in Section 3.7 to shed light on the dynamics of energy cost share on the economy and human development. As mentioned above, explanations of the results are also provided. These explanations look briefly into each country's energy history as well as its political and social background in order to shed light on the results. This could also help identify any common characteristics that could lead to similarities in energy dynamics between the nations. The main objective of this study is to compare different countries and regions; a much more in-depth study is needed to accurately explain the energy dynamics of each nation.

The section begins with the North American countries, followed by the five European countries. The BRICS nations are then analysed followed by the Australasian nations. Discretion was used throughout the analyses procedure as to where to further investigate. Although the flow of the report may seem as if the country analyses was done in a linear manner, it certainly was not. An iterative process, especially with regards to country comparisons, was followed throughout the section.

4.2.1. Canada

The year-on-year change of ECS for the time series was plotted alongside the change in GDP and GNI per capita change (seen in Figure 4.1 below). Two major peaks in ECS can be seen. The first of these occurred around 1979, where ECS rose to nearly 12%. The second peak in ECS, in 2008, rose to above 9%. A minor peak can be seen above 6% around 1990. Slightly after all three of these periods, there was a significant drop in GDP and GNI per capita change. These two metrics decreased by more than 2% during this period and up to 5% in 1982. After this drop, the indices seemed to stabilise. The economic recession in the early 1980's is commonly known to have been caused by the global oil shock due to the Iranian revolution. During this time global oil supply decreased in the Middle East. This sent oil prices, along with ECS values, extremely high. The second major recession, occurring in 2008, has been attributed to the financial crises in the USA. These two recessions are common throughout the countries analysed in this paper. For the remainder of the series, the economic and social indicators for Canada tend to oscillate around 2% growth for the region. ECS seems to be decreasing as well. It is interesting to note that when one compares GDP to GNI per capita, we see there is an extremely strong link between the two, with their values being very similar throughout the time series. GDP change is, however, always higher than GNI per capita change.

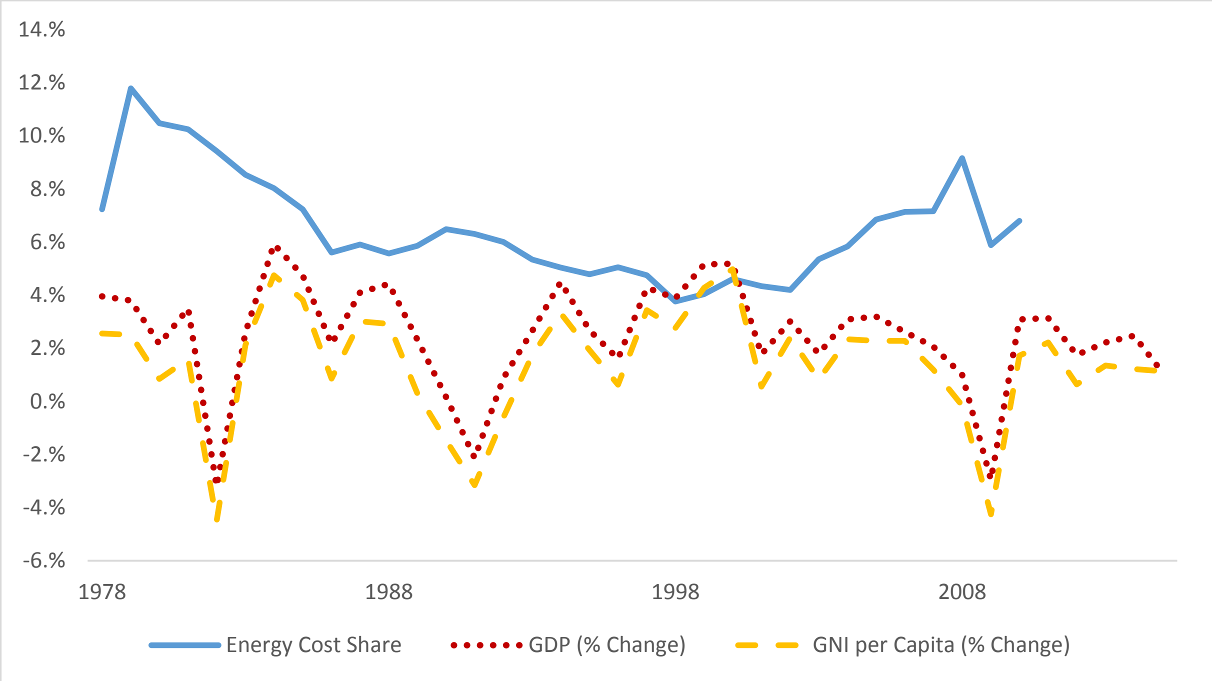

Figure 4.1: ECS, GDP and GNI per Capita Change - Canada

The oil market in Canada is particularly interesting. The country has abundant stores of oil, with most of the wells being found in the Western Canada. Almost all of these supplies are exported to the USA (NR Canada, 2017). Many of the Eastern States import oil from other countries. Looking at Canada's energy mix, it is noted that oil contributes almost 30% of the nation's primary energy supply (Canada, 2007). The Canadian economy is therefore deeply tied to the oil market as well as the US economy. This could be a major reason why the country suffered periods of low growth in the early 1980's as well as in 2009. The country has vast amounts of rivers, lakes etc. which can be used to create hydropower. All these resources may not be a good thing. The country has the highest energy consumption per capita by any of the OECD countries (IEA, 2015). The nation's average ECS is higher than that of most first world countries in this analysis, which could be attributed to the high energy consumption per capita. This could have a damaging effect on the country as fossil fuels run dry and prices increase as a result of higher EROI values. High energy intensity also means high emission rates, which could also prove a problem should emissions be taxed or traded. Recently, Canada has made large investments in producing natural gas and has put in stringent energy efficiency measures, attempting to reduce its oil demand and reduce emissions (IEA, 2015).

In Figure 4.2, ECS was compared to the health and education indices used to calculate the HDI. These indices are very high in comparison to the rest of the world, resulting in Canada being the 10th most developed country according to the HDI. Despite the turbulent nature of the ECS, the health and education indices continuously increase over the time period. No correlation could be identified and the analysis of these comparisons was not furthered.

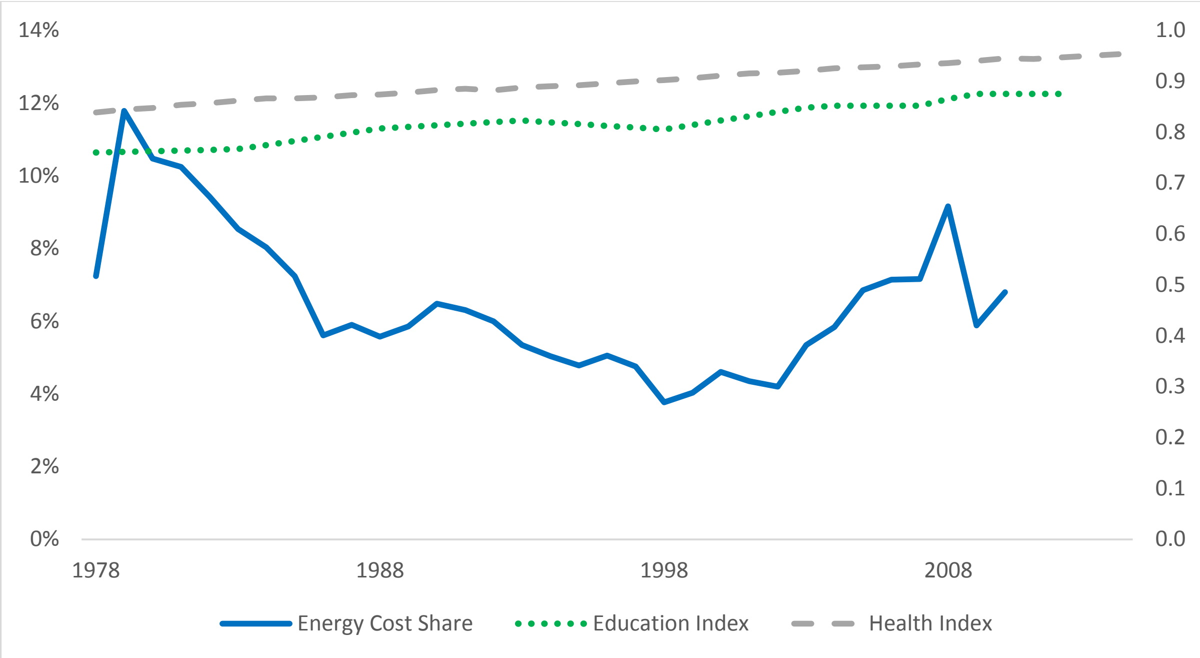

Figure 4.2: ECS, Health and Education Indices - Canada

The next step of the analyses involved identifying the strength of correlation between the change of ECS, GDP and GNI per capita change for the entire time series. Using the Pearson's Correlation test, there was a negative correlation between ECS and GDP change after one, two and three-year lags, the results can be found in Table 4.1. The only statistically significant result coming in at a one year lag, with a negative correlation of -0.319 and a *P*-value of 0.07. A similar pattern occurred when comparing the change in ECS and GNI per capita change. A statistically significant correlation was also found at a one year lag, but the negative correlation was slightly stronger at -0.354. Based on this, it can be deduced that overall changes in ECS hae a stringer correlation to GNI per capita than GDP for this nation.

Table 4.1: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Canada

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.147	0.416	-0.190	0.289
1	**-0.319**	**0.070**	**-0.354**	**0.043**
2	-0.141	0.434	-0.213	0.234
3	-0.109	0.546	-0.134	0.458

Pearson's Correlation tests were then used to test for the existence of ECS thresholds. The test was conducted using the data over short time periods, namely that of the two major peaks identified above. The results can be seen below in Table 4.2. A one year lag was seen to give the strongest correlation, similar to the results seen in Table 4.1. Overall, much stronger negative correlations were found for the ECS threshold test. Due to the small sample sizes used, however, there was greater uncertainty in the correlation, marked by the higher *P*-values.

Table 4.2 gives the results of the ECS threshold test. For the period from 1978-1984, a threshold of 7.3% was estimated (this was the lowest ECS value in the data set for this given time series). Even though a strong negative correlation was found between ECS and GDP change, the results were seen to be statistically insignificant. The same result was found when analysing the change in ECS and GNI per capita change. When looking at the period of 2005-2010, an extremely strong, negative correlation of -0.943 was found when comparing the change in ECS and GDP. Similar results were seen for the ECS vs GNI per capita change test, with a correlation of -0.907 having been established. Both these results were significant. A slightly lower ECS threshold of 6.8% was also found for this time period. These results confirm the theory of Bashmakov (2007), that an ECS threshold exists, above which GDP (and further GNI per capita) are severely affected. The exact value of this boundary is difficult to pinpoint, due to the small sample of data points used. It could be estimated, in current times at least, to be around 6.8% for Canada.

Table 4.2: ECS threshold test results – Canada

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1984	-0.464	0.294	-0.519	0.232	7.3% (One year lag)
2005-2010	**-0.943**	**0.005**	**-0.907**	**0.013**	**6.8% (One year lag)**

4.2.2. Mexico

At first glance of Figure 4.3, it can be seen that Mexico has had extremely turbulent social and economic development over the time period analysed. The year on year change in GDP ranges from about 10% to below -5% and dips below the recession mark no less than 5 times. These points are only temporary as the economy seems to bounce back the following year. The GNI per capita change index follows a similar pattern to GDP change, however, tends to be less throughout the time period. It ranges from about 7% to -9% and has 7 points on or below the recession mark. On top of the two global recessions mentioned, Mexico has experienced much political and social instability over this period. These two can be attributed to the 1983 Debt Crises and the 1995 Peso Crises (Merril & Miro, 1996). Similar to Canada, two major peaks in ECS are seen around 1979 and 2008. After these peaks, a severe drop in GDP and GNI per capita change is seen. The ECS seems to normalise around 3% for the remainder of the period. An interesting feature of Mexico's ECS curve is that the second ECS peak, seen in 2008, is higher than that of the first peak in 1980, different to that of Canada.

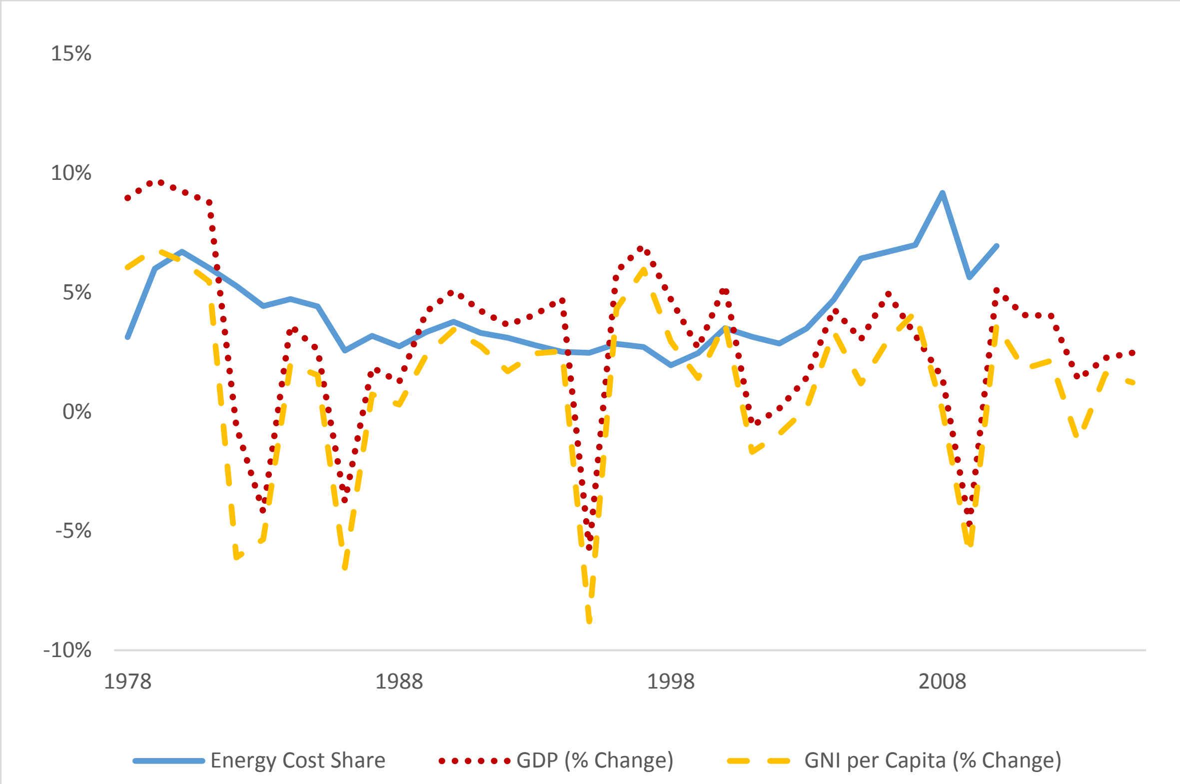

Figure 4.3.: ECS, GDP and GNI per Capita Change – Mexico

Much like Canada, Mexico is heavily involved in the oil market. This fuel provides around half the primary energy used in the country. This could be due to the oil boom that occurred in the 1970's. Oil was then a major export from this time through to the turn of the century. A shift away from oil has occurred recently due to low reserves and a low cost substitute in the form of natural gas (IEA, 2015). The economy has also furthered diversified. The strong dependence of oil as an export back in the 1980's may provide a reason for the lower ECS value than in 2009. The decreasing demand throughout the globe, due to high prices at the time, undoubtedly had an effect on the economy. As the country expanded into other sectors, it was able to withstand a larger ECS that can be seen before 2008.

The reliance on fossil fuels makes Mexico vulnerable to price increases as a result of falling fuel stock. The diversification to natural gas may only provide a temporary substitute for oil. As most of its gas supply is imported from the USA, it is reliant on its neighbour for energy supply as well as a large chunk of its economic activity.

In Figure 4.4, ECS was compared to the health and education indices selected. From the figure, one can argue that the health systems are much better than the education system when compared to world standards. There is a substantial difference between the two when scored using the HDI methodology. These two indices gradually increase over the time period and seem to have a fairly constant gradient throughout. This is a stark contrast to the volatile ECS pattern. It is evident there is very little correlation, if any, between the ECS and both the health and education indices of this nation.

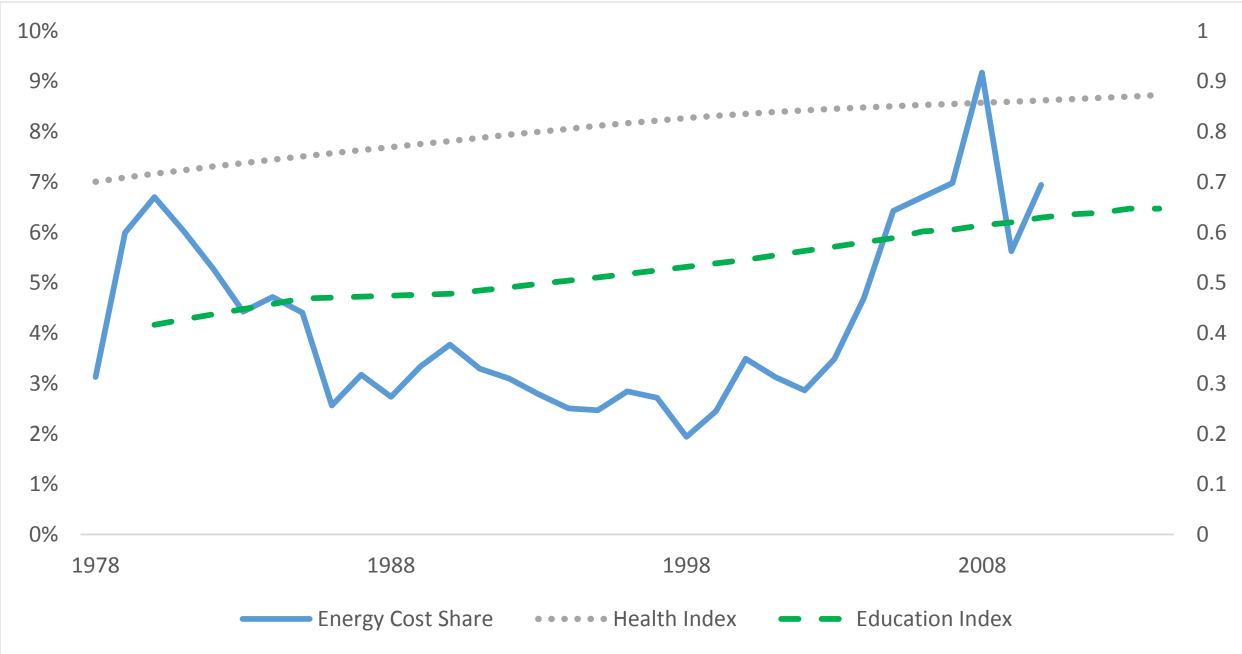

Figure 4.4.: ECS, Health and Education Indices - Mexico

Overall correlations to the ECS were then obtained for both GDP and GNI per capita change, the results can be seen in Table 4.3. When comparing the strength of correlations, it was seen that a negative correlation was obtained for one, two and three year lags, with the correlation growing as the number of years lagged increased. Mexico, being a third world country, relies heavily on foreign investment for economic growth. As global growth slowed, especially for the two major recessions around, 1979 and 2008, investment from many first world nations may have slowed (Unctad, 2017). The lack of investment in the region may have shown in the following years. The results, however, were seen to be statistically insignificant as *P*-values for the correlation tests were above 0.1. The volatile economic market, with other factors severely affecting GDP and GNI per capita change, makes it difficult to establish a sound correlation. What can be determined is that over this period, energy price did not play a major role in economic recessions for the country of Mexico.

Table 4.3.: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Mexico

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	0.159	0.375	0.152	0.398
1	-0.132	0.463	-0.156	0.385
2	-0.169	0.347	-0.192	0.286
3	-0.264	0.138	-0.282	0.112

From the ECS threshold test (the results are in Table 4.4), it can be seen that there was a high correlation between ECS and GDP change, as well as ECS and GNI per capita change. The period from 2005-2010 produced significant results, with a high, negative correlation of -0.958 between ECS and GDP change. The correlation was similar for GNI per capita change, at -0.934. Being so closely linked to the US markets, Mexico suffered severely during the 2008 recession. As the massive US economy slowed, the demand for fuel sources reduced. From this test, a threshold for this time period can be deduced at around 6.4%. More sample points and a stronger correlation are needed for the time period of 1978-1982 to produce significant results.

Table 4.4.: ECS threshold test results – Mexico

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1982	-0.815	0.185	-0.592	0.408	5.3% (One year lag)
2005-2010	**-0.958**	**0.004**	**-0.934**	**0.006**	**6.4% (One year lag)**

4.2.3. USA

Figure 4.5 shows that the ECS of the USA has a similar shape to those of the other countries in its region, with two peaks around 1979 and 2008. In contrast to its neighbours, the US has a decreasing ECS trend over the time series. The peak in ECS 1979, around 10%, was much higher than that of 2008, which just breaches 6.5%. With average GDP chhange for this country around 2.7% over the time period, there are significantly lower periods of growth after the two peaks in ECS. Interestingly, after the initial reaction to first ECS peak, we see a recovery of the economy in 1981. This is then followed by another year of recession before the economy begins to climb. This ‘aftershock' could be due to the fact that policies may have been put into place after the collapse in 1980, allowing the economy to recover and grow in 1981. Energy prices, however, were still high at the time and these measures were stifled. It was only after energy costs had dropped low enough that growth could resume. The GNI per capita change follows a very similar pattern to that of the GDP change index, but its growth rate is constantly lower throughout the period. In 1991, it can be seen that GDP remained constant, however, GNI per capita decreased by 1.7%. This difference is important to consider when considering energy policies, as energy expenditures may be correlated to social situations more so than economic ones.

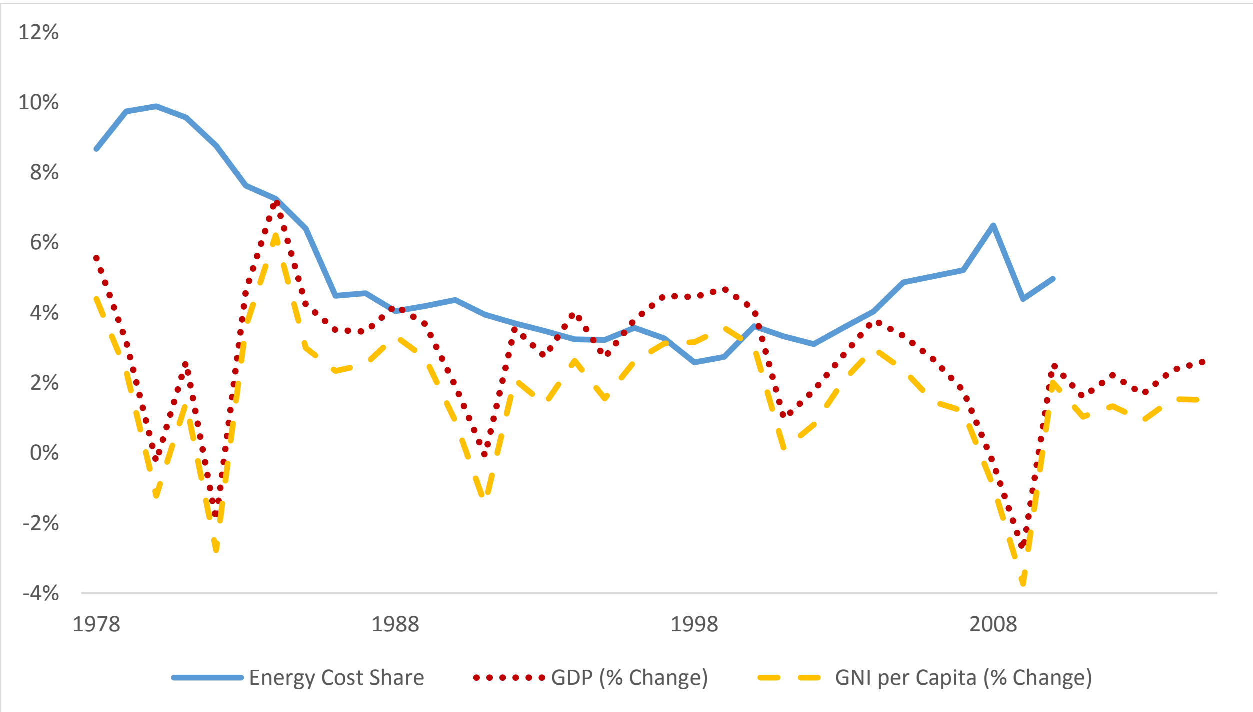

Figure 4.5.: ECS, GDP and GNI per Capita Change – USA

Figure 4.6 shows the ECS in comparison to the health and education indices. These two social indices are extremely high in comparison to world standards and increase gradually over the time period. The only anomaly is a slight decrease in the education index for the year 2000. There was seen to be no correlation between ECS and these two indices, therefore, no further analysis was conducted.

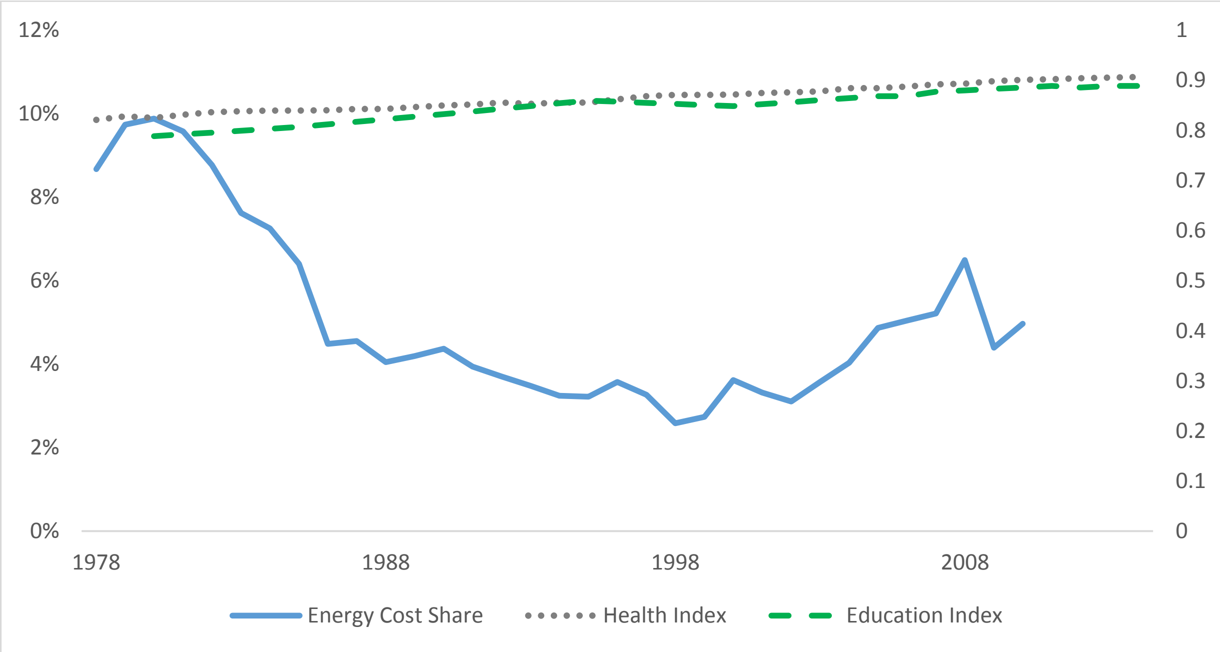

Figure 4.6: ECS, Health and Education Indices - USA

Using the correlation test, it was established that a negative correlation between GDP change and ECS existed for a one and a two year lag, as seen in Table 4.5. The economy had then recovered, causing a positive correlation in the third year. A similar pattern followed for the GNI per capita change. These results did not, however, meet the statistical significance standards.

Table 4.5: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - USA

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.129	0.473	-0.106	0.556
1	-0.249	0.163	-0.240	0.178
2	-0.102	0.571	-0.093	0.609
3	0.070	0.7	0.083	0.645

The ECS threshold test for the USA provided interesting results and can be seen in Table 4.6. The tests show that during the period from 1978-1983 there was an extremely strong, negative correlation between energy expenditure and GDP change, with a correlation coefficient of -0.839. This correlation was even stronger for the period from 2005-2010, giving a coefficient of -0.960. Both of these results were seen to be statistically significant. This conforms to the theory put forward by Bashmakov (2007). An interesting point to mention is that the correlation between ECS and GNI per capita change was stronger than that of ECS and GDP change for the corresponding period. This further emphasises the fact that social standards have a stronger correlation to energy expenditure than economic growth. Another interesting point is that the ECS threshold decreased, from 7.6% for the period of 1978-1983, to 4.9% for the period of 2005-2010. The first of the ECS thresholds is much higher than that of Bashmakov (2007) and Aucott & Hall (2014) who predicted a threshold of between 4-5% and 4% respectively. The second of the ECS thresholds of 4.9% is, however, much closer to these studies. The variation between these could be due to different data sources being used. Aucott & Hall (2014) used costs of fuels used to create the energy needed whereas Bashmakov (2007) used final price data paid by consumers. This study more closely resembles the methodology used by Bashmakov (2007), however, data sources were different. Bashmakov (2007) was able to generate a longer time series for the US, giving greater clarity on an estimated threshold.

Table 4.6: ECS threshold test results – USA

Years	GDP Growth		GNI per Capita Growth		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1983	**-0.839**	**0.037**	**-0.843**	**0.035**	**7.6% (One year lag)**
2005-2010	**-0.939**	**0.005**	**-0.960**	**0.002**	**4.9% (One year lag)**

The fact that the estimated threshold changed between the two periods could be explained by three reasons. Firstly, the actual threshold could be around 5%, as postulated by Bashmakov, but as our time series starts at a point when the ECS is already above this threshold, it is difficult to gauge what the exact point of this threshold is. The ECS may have surpassed this threshold before 1978, but we would not be able to identify that from the data being used. The data for this period, though, still has much use. It tells us that, if the ECS is above 7.6%, the economy and social well-being is highly dependent on ECS. The second reason could be that the ECS threshold does exist in the region of 7.6%, however, another event may have triggered an economic recession while the ECS was climbing towards this mark. The financial crises of 2009 is widely regarded as the main reason for the economic recession. This collapse then caused a major reduction in fuel demand, and therefore prices, leading to a reduction in ECS. The final reason could be that, even though the average ECS of this nation decreases over the period, social and economic development the correlation to energy expenditures has strengthened in the US. This is especially true when a threshold is exceeded. As fossil fuel sources dwindle, and prices fluctuate, this high level of dependency could come with serious ramifications. Furthermore, much of the world is dependent on the state of the US economy, making this a global concern.

4.2.4. France

Figure 4.7 shows that the ECS of France over the time period is characterised by the two peaks, common to most of the countries being analysed. The first peaking at 7.2% and the second just under 6%. After the effects of the first peak, the ECS is seen to slowly decrease from around 4% to 2.5%, before the inclination towards the second peak begins. As seen before, there is a significant drop in GDP and GNI per capita change following these peaks. The first of which resulted in GDP change to drop to 0.6%, with GNI per capita change dropping even lower at 0.1%. The second peak in 2008 is followed by a much more drastic reaction by these two metrics. These indicators decreased by almost 4% for the year of 2009. This is interesting to note that, even though the second peak in ECS was lower than that of the first peak in 1979, the social and economic indicators fall more sharply during the second peak. Two other drops in GDP and GNI per capita change also occur over the time period. The first of these happens the period from 1990-1993, the same time as the stock market crash. The second slowdown in the performance of these indices occurs around 2002.

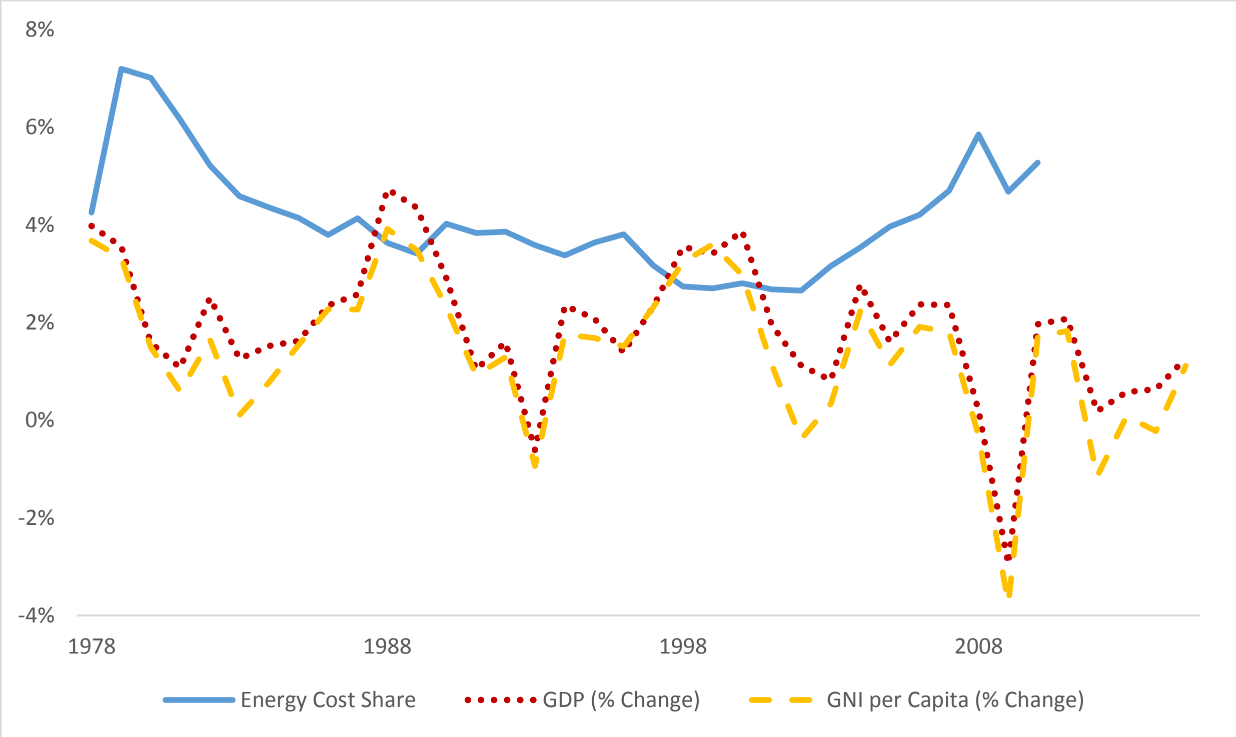

Figure 4.7: ECS, GDP and GNI per Capita Change - France

Figure 4.8 below shows that the health index of France experienced gradual increase over the time period. The French health index is currently is very high in comparison to world standards. The education index is also at a very high standard, especially after a significant increase in the education index beginning in the late 1980's. The graph clearly shows that there is no correlation between the ECS and these two social indices.

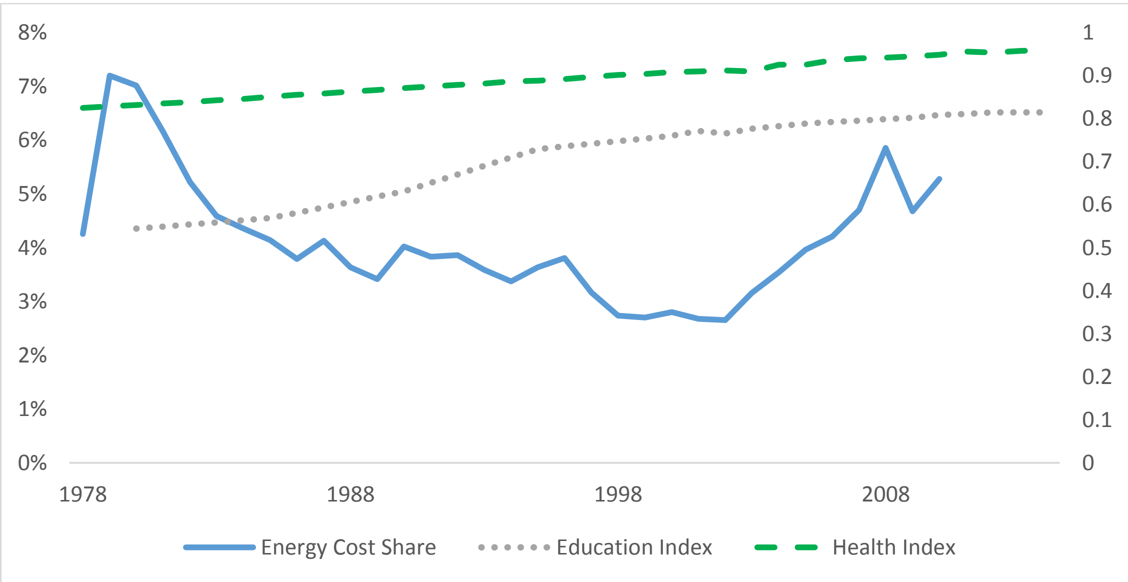

Figure 4.8: ECS, Health and Education Indices – France

A statistically significant correlation was found for the entire time period between the ECS and GDP change, that being -0.340 (seen in Table 4.7). This was similar to the correlation between the ECS and GNI per capita change. It can be deduced that any changes in energy expenditure are negatively correlated to the two indices with a one year lag. Furthermore, this change will affect the economy slightly more than social standards. Negative correlations were also found for two and three year lags however these correlations were statistically significant.

Table 4.7: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - France

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.182	0.301	-0.149	0.438
1	**-0.340**	**0.053**	**-0.315**	**0.074**
2	-0.204	0.255	-0.230	0.198
3	-0.100	0.578	-0.124	0.491

The results in Table 4.8 show an extremely strong, negative correlation between ECS and GDP change when a threshold of 4% has been surpassed. The time period from 2005-2009 produced a significant correlation coefficient of -0.949. A similar situation occurred when comparing ECS to GNI per capita change, with a correlation coefficient of 0.940 being produced. These results mimicked the results in Table 4.7 before, as both the significant correlations occurred in after a one year lag and the ECS vs GDP change correlation is slightly stronger than the ECS vs GNI per capita change correlation.

Table 4.8: ECS threshold test results – France

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1983	-0.718	0.172	-0.494	0.398	4.3% (One year lag)
2005-2009	**-0.949**	**0.013**	**-0.940**	**0.018**	**4% (One year lag)**

A significant portion of France's energy comes from nuclear power. After the 1979 oil price shock, the country looked to reduce its dependence on oil (Mearns, 2013). Having very few natural resources available it looked to nuclear energy. The country is still very dependent on oil and natural gas, as can be seen by the slow growth from 2005 onwards in Figure 4.7, where there is a high ECS. France is in the process of replacing its current fleet of nuclear reactors and it will be interesting to see how the economy and society will react to the new, higher prices needed for this infrastructure upgrade (Mearns, 2013).

4.2.5. Germany

The ECS of Germany, shown in Figure 4.9, is slightly different to that of other countries. The peak in ECS is around 12% at 1979 and steadily decreases to below the 3% mark in 1999, more than twenty years. Other countries tend to recover from this jump in energy expenditure in a much shorter time frame, usually around eight years. The ECS then begins to climb again towards a second peak of 7% in 2009. The high ECS in the late 1970's could be due to the fact that Germany, especially Western Germany was extremely industrialised in comparison to the rest of the world. Other countries with high levels of development at this stage, such as the USA, UK and Canada, also experience a high ECS peak in the late 1970's. The tendency for the ECS to decrease over the period where peaks are not experienced could be due to greater technological developments and efficiencies achieved in energy conversion technology.

The two peaks in ECS are followed by periods of low social and economic development. The more severe of which occurs after the second peak where GDP change decreases by almost 5%. There was also a minor peak that occurs during the recovery of the initial peak in 1987, however, GDP and GNI per capita change were not severely affected. Other periods of low economic and social development also occur around 1993 and 2002. The graph also shows us the close relationship between GDP and GNI change, with the two lines often crossing over each other. This was uncommon in the North American countries, where GNI per capita change always fell below that of GDP change.

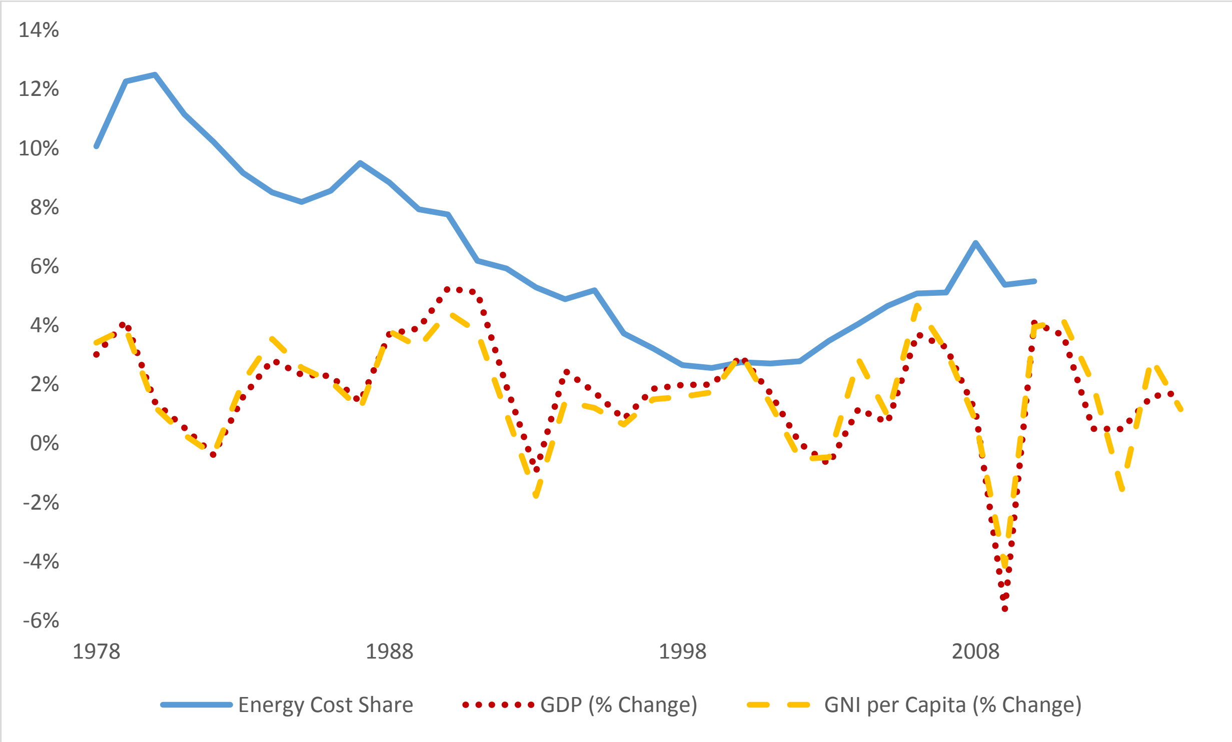

Figure 4.9: ECS, GDP and GNI per Capita Change - Germany

The ECs, health and education indices graph, seen in Figure 4.10, shows a similar pattern to France - very high levels of health that are continuously improving. The current education index is also extremely high, after a sudden increase from 1990. Little correlation could be seen between these two indices and the ECS of the nation.

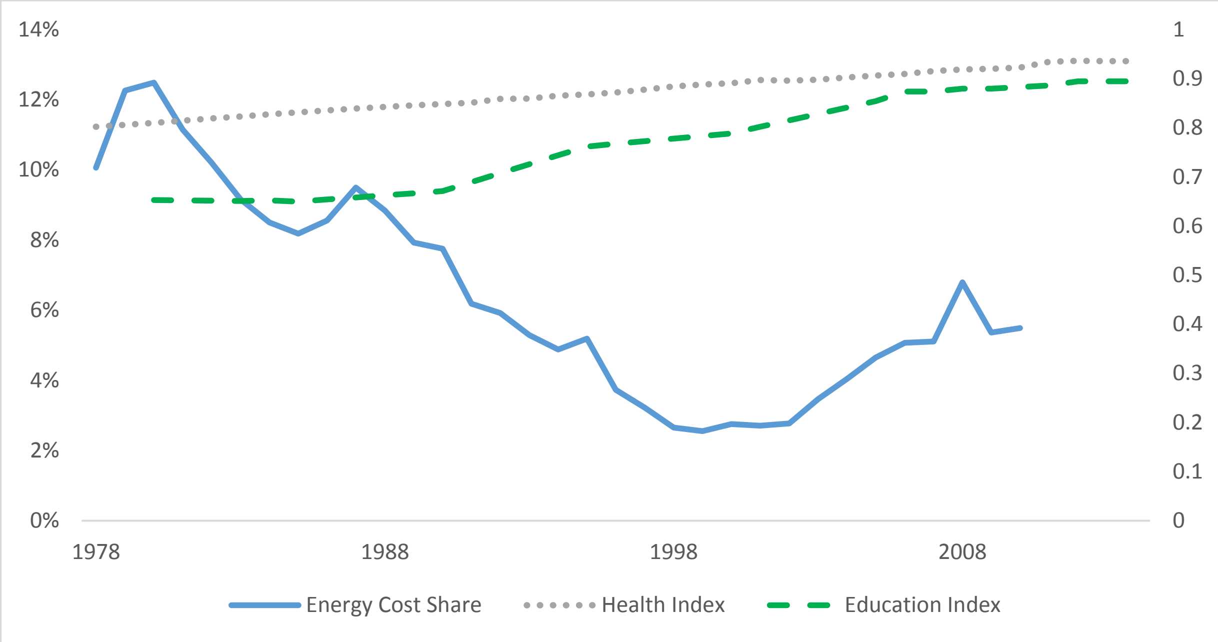

Figure 4.10: ECS, Health and Education Indices - Germany

The results from the overall correlation tests, seen in Table 4.9, show that there was very little correlation between ECS and both GDP and GNI per capita change for one, two and three year lags. This makes sense, as there was turbulent economic and social developmet during a period where the ECS of the country gradually declined after the initial peak. All of these results were seen to be insignificant.

Table 4.9: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Germany

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	0.171	0.340	0.193	0.281
1	0.089	0.622	0.083	0.647
2	0.148	0.410	0.102	0.572
3	0.173	0.334	0.129	0.491

The ECS threshold test, the results of which are seen in Table 4.10, showed a greater correlation between ECS and GDP change, as well as GNI per capita change, than in Table 4.9. A high, negative correlation was found over the initial twelve-year period between GDP growth and ECS. A similar result was obtained for GNI per capita change and ECS, a correlation of -0.621. Using a large sample of data points increased the statistical significance results, reducing the uncertainty over the correlation values obtained. Over the period of 2006-2010, an even higher correlation was established between ECS and GDP change. This was mirrored by the ECS and GNI per capita change correlation. Even though a small set of points were used, strong correlations could be identified, giving credence to the tight relationship between the metrics. The thresholds estimated were similar to that of the US in two ways. Firstly, both thresholds decreased between the two time periods and, even though the second threshold was smaller, it produced a higher, negative correlation between both the metrics. Secondly, the estimated thresholds for each corresponding time period are very similar. The estimated threshold for the USA at the initial ECS peak was 7.6%, compared to that of 7.9% ECS threshold for Germany. The estimated ECS threshold for the second peak was 4.9% in the USA, compared to a 5.1% ECS threshold for Germany. This relationship could be due to the high development of both countries, leading to similar behavioural patterns, as well as ECS thresholds. The results of these two countries back up the theory of Bashmakov (2007) that states energy expenditure has little impact on economic growth unless a threshold has been breached.

Table 4.10: ECS threshold test results – Germany

Years	**GDP Change**		**GNI per Capita Change**		**Estimated ECS Threshold**
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1989	**-0.626**	**0.029**	**-0.621**	**0.031**	**7.9% (One year lag)**
2006-2010	**-0.854**	**0.065**	**-0.835**	**0.078**	**5.1% (One year lag)**

The German energy market is quite remarkable in a few ways. Firstly, total primary energy consumption has continued to decrease since 1979 oil price crises. Most countries have an increasing energy consumption rate due to an increase in population and a growing economy. Germany was able to absorb the demand for energy due to a population increase by improving energy efficiency within the country (Mearns, 2013). Although to a lesser extent than France, Germany also increased its nuclear capacity after 1979. It has recently begun replacing this fleet with renewable energy.

Driven by innovative policies for clean energy, the country was able to increase its renewable energy supply to the electricity sector from 6% in 2000 to 34% in 2016 (Mearns, 2013). This surge in renewable energy, as well as Germany's energy efficiency measures, have made the country the poster child for a low carbon transition. The country's strong economy has definitely facilitated this transition as other countries may not have been able to afford to put such inviting policies in place. The story of Germany does send a message to other large, fossil fuel intensive economies that a transition to a cleaner energy mix can be made. Furthermore, it shows all nations of the globe that growth is not strictly dependent on energy consumption, an important point to make in the face of declining fossil fuel reserves. Germany's foresight in the energy market may put it on strong economic footing in the years to come.

4.2.6. Italy

The ECS shape of Italy over the time period, shown in Figure 4.11, is similar to most countries. There is a peak in 1979, going just below 6%, followed by a recovery period. After this, the ECS stabilises around the 2.5% mark until 2002. It then increases towards a second peak of 6% in 2008. The GDP and GNI per capita change figures respond to these two peaks. The second response, however, is much more drastic than any of the other periods of poor economic performance, and the GDP shrinks by more than 5% in 2009. The GDP and GNI per capita change indices are closely linked and often overlap each other throughout the period. What is common to most other countries, but is much more pronounced in the case of Italy, is the presence of a second year of poor economic performance after the second peak. Most countries have poor growth figures in 2009, followed by a year or two recovery period. It is at this point, around 2012, that the GDP and GNI per capita change figures show a decrease in economic and social standards. A reason for this could be the fact that the ECS for these countries never fully decreases back down to average levels after 2009. The ECS figures peak in 2008, decrease slightly in 2009 and then seem to rise again in 2010. The second dip in economic performance may be as a result of the ECS values still being above, or near to, the ECS threshold and still have a negative correlation to GDP and GNI per capita change. In theory, periods of low economic development should decrease the demand for energy and thus reduce energy costs (Bashmakov, 2007); (Aucott & Hall, 2014). This does not happen during this time period. This could be due to the inflexible prices of fuels as a result of dwindling resources, as discussed in Section 2.5. Energy sources with higher EROI values are having to be exploited and this is resulting in an increase in cost. Another reason could be that the economic recession did not last long enough to allow for the energy prices to stabilise. It took most nations about three years to recover from the economic recession seen in the late 1970's. Over this time, the ECS figures dropped drastically. This was not the case for the second recession seen in 2009. Many of the banks causing the financial crises of 2008 were bailed out very soon, ensuring the economy sharply recovered. This may have allowed ECS values to remain high and, in turn, keep its grip on economic and social development.

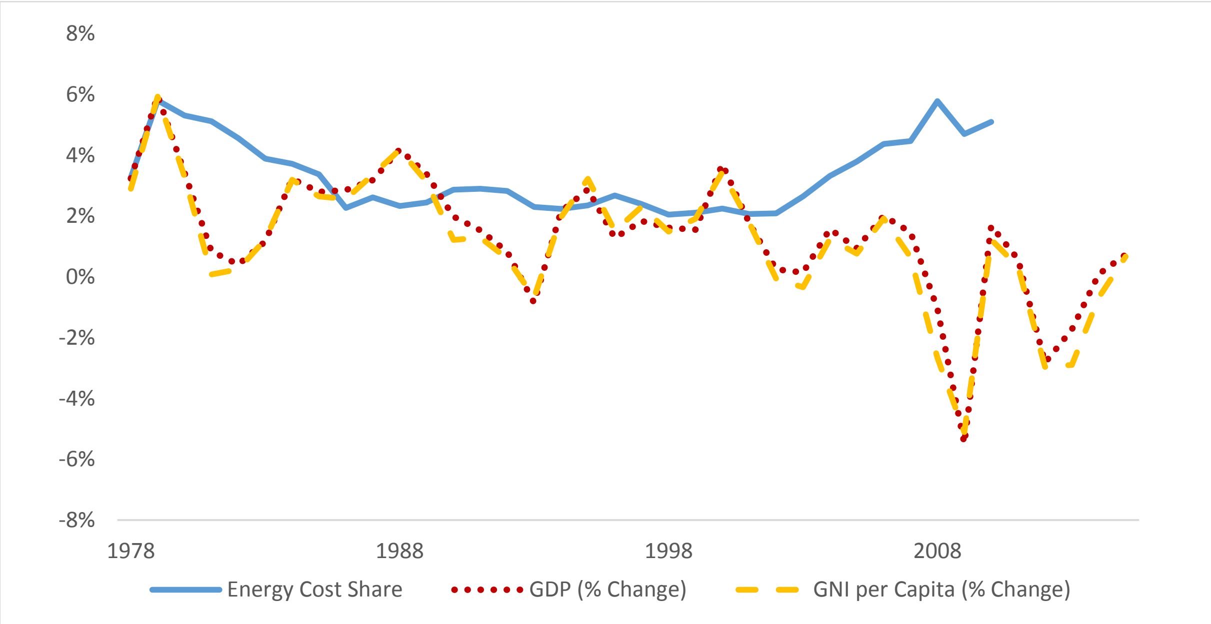

Figure 4.11: ECS, GDP and GNI per Capita Change - Italy

The social indicators of Italy in Figure 4.12 show a similar pattern to the other countries analysed in Europe. Both are very high in comparison to the rest of the world. With the health index seen to be much higher than the education index throughout the period. These two indices steadily increase over the period, in spite of a rapidly changing ECS. It is clear from this graph that there is no correlation between the two indices and ECS of Italy.

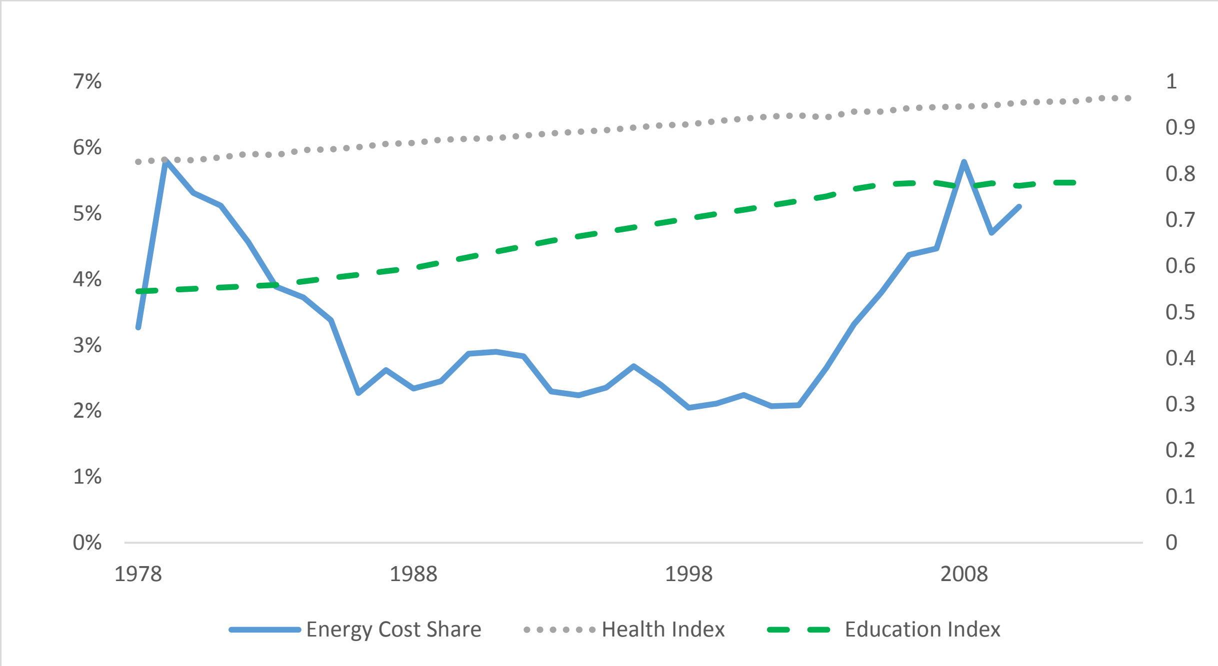

Figure 4.12: ECS, Health and Education Indices - Italy

Noteworthy results were found when conducting an overall correlation between the ECS and GDP change, seen in Table 4.11. Significant, negative correlations were found for both one and two year lags. Furthermore, these correlation coefficients were very similar. The correlation between ECS and GNI per capita change followed the same pattern of producing similar, negative correlation for a one and two year lag. These correlations were also higher than that of ECS vs GDP change.

Table 4.11: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Italy

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.132	0.465	-0.211	0.239
1	**-0.351**	**0.045**	**-0.381**	**0.029**
2	**-0.334**	**0.05**	**-0.375**	**0.031**
3	-0.274	0.123	-0.287	0.105

Taking into account that an ECS change may affect Italy after two years, an ECS threshold test was taken for one and two year lags for the periods of high ECS values (seen in Table 4.12). It was found that a two year lag produced a greater negative correlation coefficient when comparing ECS and GDP change. A similar situation was found when comparing ECS and GNI per capita change. Negative correlations were found for a one year lag for these two indices, but the results were not significant and were, therefore, not reported. The estimated ECS thresholds established were very similar for both periods of high ECS peaks. More noteworthy is the fact that these thresholds are very low, similar to the estimated, further emphasising that economic and social metrics have very strong correlations to energy expenditure.

Table 4.12: ECS threshold test results – Italy

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1983	**-0.854**	**0.029**	**-0.885**	**0.019**	**3.9% (Two year lag)**
2005-2010	**-0.809**	**0.0051**	**-0.735**	**0.096**	**3.8% (Two year lag)**

4.2.7. Spain

Figure 4.13 shows us a great example of the inverse relationship ECS can have with GDP and GNI per capita change. The two major ECS peaks, as well as a mini peak from 1990-1993, are followed by periods of low economic and social development. Fascinatingly for the case of Spain, periods characterized by low ECS values (1985-1989; 1997-2002) are closely followed by high GDP and GNI per capita change. This may be an exception to the proposition posited by Bashmakov (2007) as the economic development is not only affected once the ECS has surpassed a threshold, it is also affected during periods when energy expenditure is low. Assuming Bashmakov's (2007) theory to be true for all countries, it could be that the ECS threshold for Spain may be extremely low and that the ECS for this time period is constantly above this threshold. There is also a great degree of variance in growth patterns between GDP and GNI per capita change, especially after 1993, causing the GDP and GNI per capita change lines to be separated by more than 2% in some years.

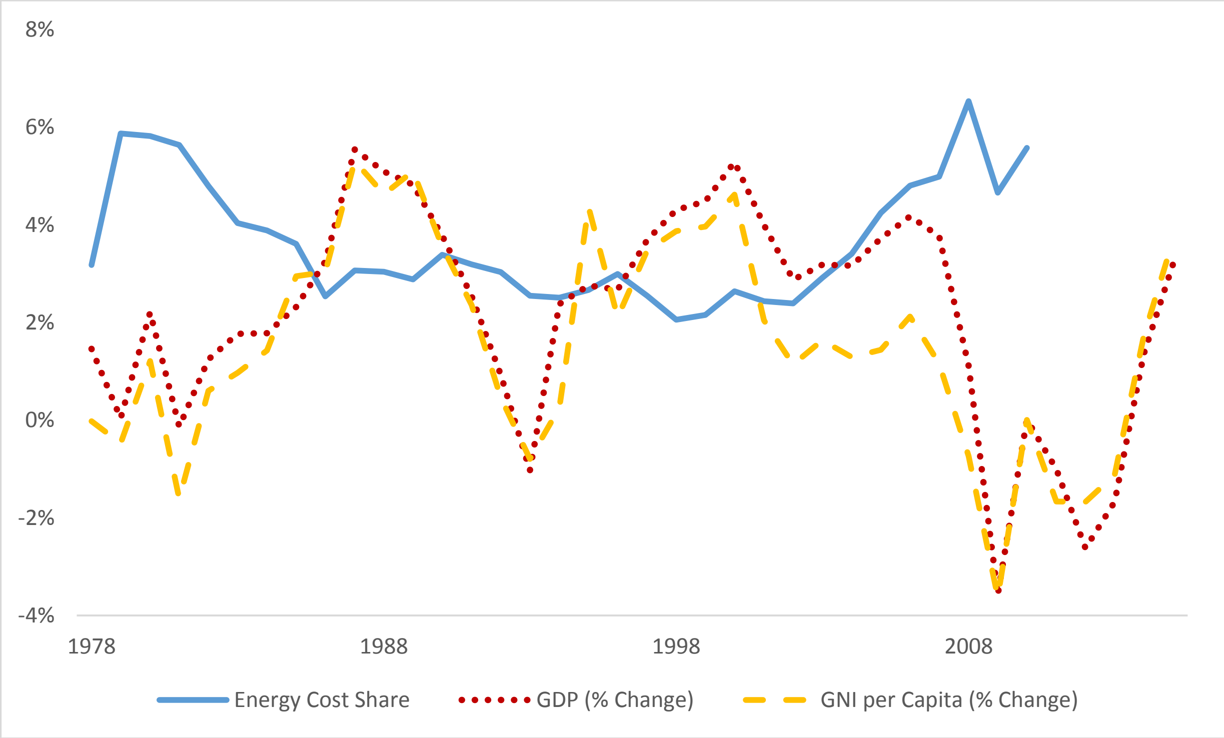

Figure 4.13: ECS, GDP and GNI per Capita Change - Spain

In many ways, the Figure 4.13 is similar to that of Figure 4.11 of Italy. The first ECS peak seen in 1979 is not very high compared to other countries in the region, however, second ECS peak occurring in 2008 is as big, or slightly larger in the case of Spain. Furthermore, there is a second decline in economic and social standards three years after the financial crises in 2008.

Figure 4.14 depicting the relationship between the ECS and the two social indices, health and education, are very similar to those of other European countries. The state of health and education seem to grow steadily over the time period, with an acceleration in the education index from the late 1980's. The ECS, on the other hand, has large fluctuations, alluding to the proposition that it has no bearing on these indices.

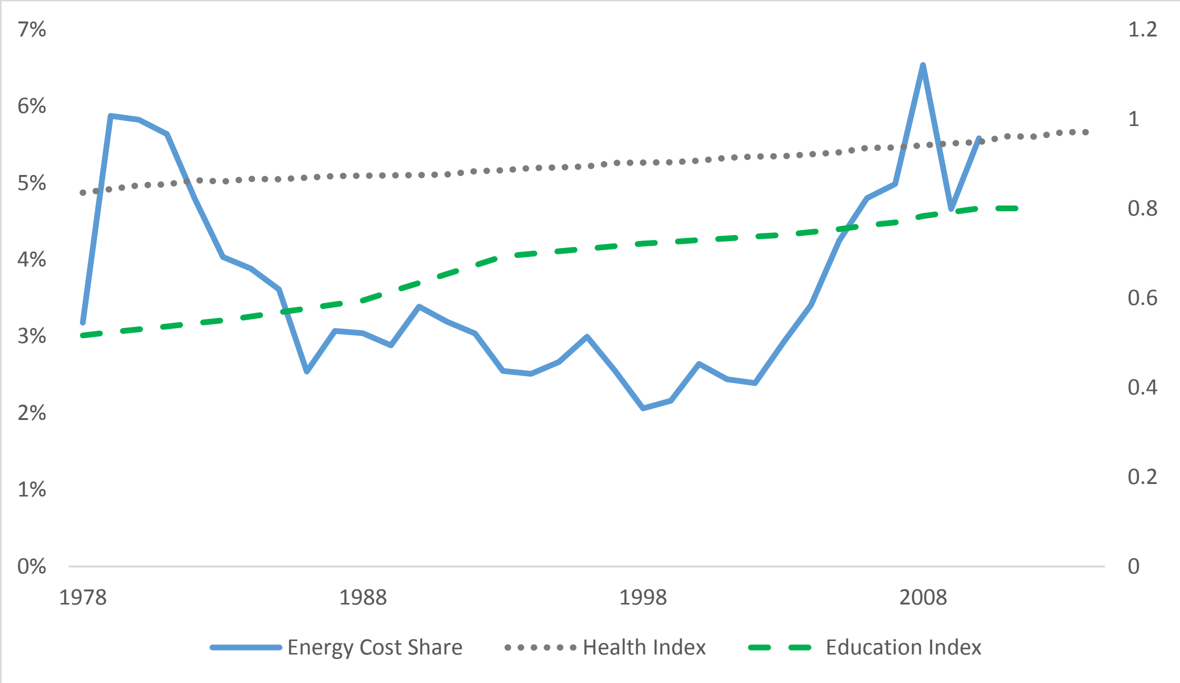

Figure 4.14: ECS, Health and Education Indices - Spain

The close relationship between ECS, GDP and GNI per capita change was backed by the results seen in Table 4.13. Spain produced by far the strongest negative correlation coefficients for any country analysed for the entire time period. Another important finding is that a significant a correlation was established for a zero lag. Theories by Bashmakov (2007), Fizaine & Court (2016) and King (2015) postulate that energy expenditure tends to have a correlation to economic development in years following a price spike. The results show that there are exceptions to this theory

Furthermore, significant negative correlations were obtained over zero, one, two and three year lags. This allows us to compare how GDP and GNI per capita change react to a shift in energy expenditure. The economy seems have a strong correlation over all three years, with a very slight recovery in the third year. The GNI per capita change figures are severely affected in the first year after a shift in ECS, more so than GDP change, however, the correlation seems to weaken much faster. Much like Italy, Spain is heavily reliant on oil for energy production, with almost 45% coming from this source of fuel (Mearns, 2013). These values were even higher over the global economic recessions in 1979 and 2008. This is possibly why Spain's economic and social standards not only decrease following high energy expenditure, but also increase after periods of low ECS. There have been major strides in renewable energy in Spain in order to diversify its energy mix and reduce its reliance on oil, but these have brought further financial issues as many projects were introduced as the global economy collapsed in 2009.

Table 4.13: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Spain

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	**-0.480**	**4.7E-3**	**-0.570**	**5.3E-4**
1	**-0.649**	**4.1E-4**	**-0.671**	**1.9E-5**
2	**-0.661**	**2.9E-5**	**-0.610**	**1.6E-3**
3	**-0.594**	**2.7E-3**	**-0.467**	**0.006**

Due to the significant correlation coefficients found for one, two and three year lags, a similar methodology was followed to that of Italy's ECS threshold test, whereby all these lags were considered to find the ECS threshold. The results of which are in Table 4.14. For the period form 1973-1983, significant results were obtained for the correlation between ECS and GDP change for a two year lag. Strong, negative correlation between ECS and GNI per capita change was also found, but the uncertainty was seen to be too high. For the second ECS peak, significant results were obtained for both the social and economic indicators, with an extremely strong correlation between ECS and GNI per capita change of -0.962. This was the strongest correlation seen by any country in both the overall and threshold correlation tests. The fact that these correlations are stronger than those of the overall correlations obtained in Table 4.13 indicates that there is an ECS threshold for the country, above which social and economic development is more vulnerable to changes in ECS. It is interesting that a two year lag was seen to produce stronger correlations in the period from 1978-1983, yet this shifted to a one year lag in the more recent period. The correlation coefficients for the period of 2005-2009 were also much higher than those of the previous period. These results could argue that the Spanish economy and society have become more affected by ECS as time continued. Thereby allowing the effects of a shift in ECS to be more sudden. The large difference between the correlation coefficients of ECS and GNI per capita change for the first period and the second indicate that society's dependency on energy expenditure to grow has become especially strong.

Table 4.14: ECS threshold test results – Spain

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1983	**-0.736**	**0.095**	-0.756	0.139	**4% (Two year lag)**
2005-2009	**-0.855**	**0.030**	**-0.962**	**0.002**	**4.3% (One year lag)**

4.2.8. The United Kingdom

The shape of the ECS line shown in Figure 4.15 is almost identical to that of the USA. Both ECS lines peak slightly above 10% in 1979, followed by a long period of decline. This decline is sharp at first, but becomes more gradual from about 1985. The ECS then stabilises around 3% during the 1990's before climbing up to second ECS peak just above 6% in 2008. Furthermore, the contraction of the economy and societal well-being is much sharper following the second ECS peak, even though this peak is much lower than the first. The GDP and GNI per capita change figures of the UK follow similar paths from the start of the time period until about 2005. From this point, it seems that economic development is significantly higher than social development. It could be said that the economy may benefit more from low energy expenditure. Following two periods of high ECS, both the GDP and GNI per capita change decreased in the same fashion, indicating both correlated to high energy expenditure.

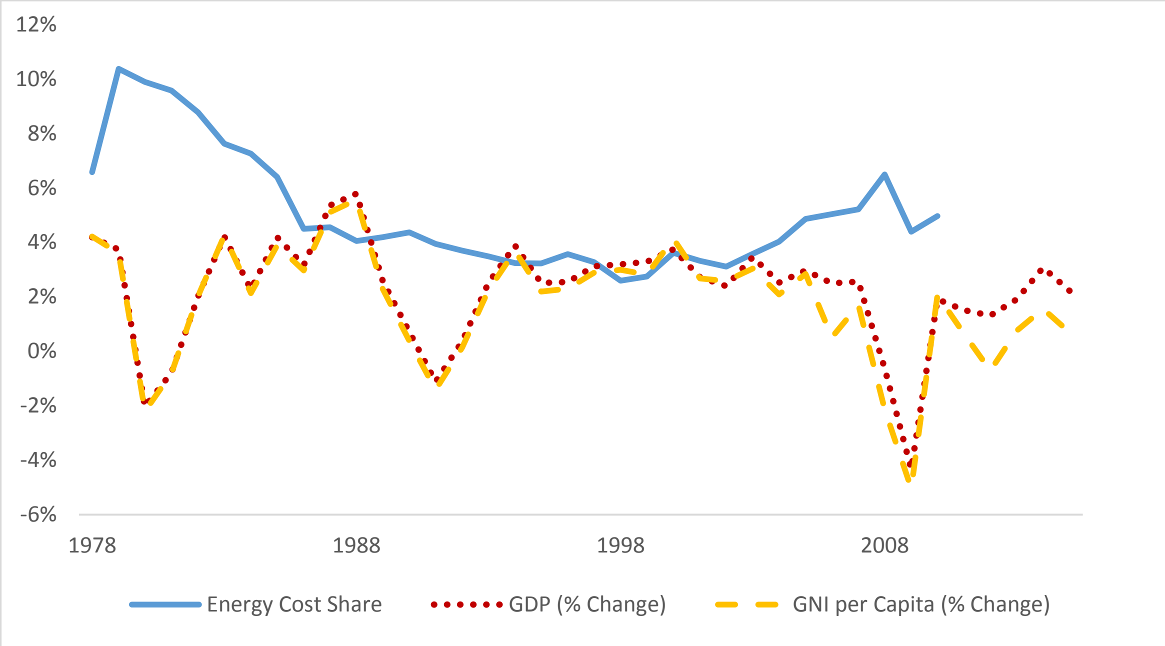

Figure 4.15: ECS, GDP and GNI per Capita Change – The United Kingdom

Figure 4.16 shows that the health and education indices of the UK follow a similar pattern to that of the rest of Europe. The education index, however, is significantly higher than the other countries analysed within the continent. From the graph, it can be seen that there is very little correlation between these indices and the ECS of the nation.

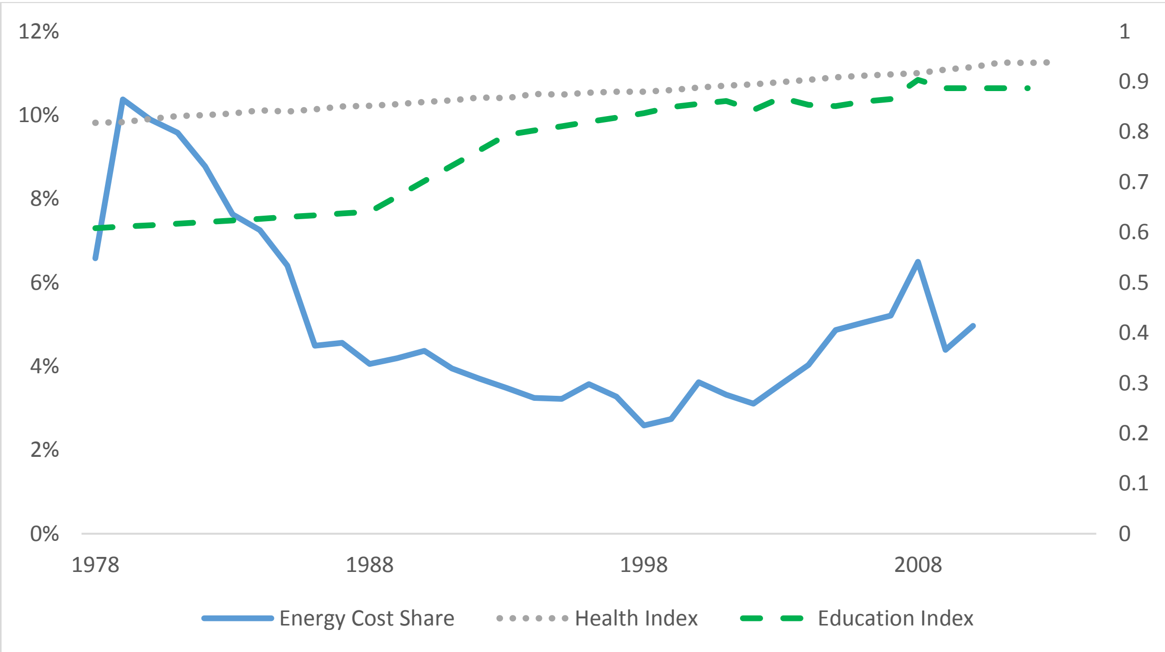

Figure 4.16: ECS, Health and Education Indices – The United Kingdom

The results from the overall correlation test shown in Table 4.15 indicate that ECS has a negative correlation to GDP and GNI per capita for a one year lag. After which these indices recover. Significant, negative correlations were found after a one year lag for both the GNI per capita and GDP change, with a slightly stronger correlation being found for the latter.

Table 4.15: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags – The United Kingdom

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.213	0.235	-0.189	0.291
1	**-0.337**	**0.055**	**-0.301**	**0.088**
2	-0.128	0.479	-0.082	0.652
3	-0.108	0.548	0.135	0.454

The ECS threshold test results, shown in Table 4.16, indicate a strong presence of an ECS threshold for both economic and societal growth. For the first period of high ECS, a correlation coefficient of -0.884 was established between ECS and GDP change. This value increased slightly when the correlation test was performed over the second period from 2005-2010. This is in contrast to the correlation between ECS and GNI per capita change. The correlation strengthened significantly between the two periods. This indicates that high energy expenditure has a stronger correlation to GDP and GNI per capita in recent times.

Table 4.16: ECS threshold test results – The United Kingdom

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1984	**-0.884**	**0.041**	**-0.804**	**0.029**	**6.6% (One year lag)**
2005-2010	**-0.900**	**0.014**	**-0.910**	**0.011**	**4.9% (One year lag)**

Similar to Germany and the USA, the correlations between ECS, GDP and GNI per capita change become much stronger over the second period of high ECS from 2005-2010. This is in spite of the much lower ECS threshold estimated than for the previous period from 1978 to the mid-1980s. This could indicate that these developed countries have a stronger correlation on energy expenditure for economic and societal development as time has gone on. If this is the case, turbulent times could be ahead as fossil fuel prices continue to increase as they begin to run out. Another interesting point is that the estimated thresholds for all three of these nations are very similar, for both time periods. For the first period of high ECS values, the estimated ECS threshold values for the UK, USA and Germany were 6.6%, 7.6% and 7.9% respectively. The estimated ECS for the UK was slightly lower than the other two, but it is still much higher than those obtained by the Mediterranean countries of France, Italy and Spain (around 4%). These values become even closer for the second period of high ECS starting in the mid-2000's. The estimated ECS threshold values for the UK, USA and Germany were 4.9%, 4.9% and 5.1% respectively. Analysing the energy mixes for each country, we see that the UK and Germany have similar trends in energy mix over the period. The composition of oil and coal within their energy mix decreases over the time period, with an increase in natural gas, nuclear and renewable energy. The growth in natural gas is much more rapid in the UK than in Germany, which has attempted to substitute oil and coal with more nuclear and renewable sources (Mearns, 2013). In a similar fashion, the US has decreased its composition of oil in its energy mix, however, it has substituted this with a larger input from coal as well as natural gas. Nuclear and renewable energy resources are also increasing, but not at the rate seen in Germany (Mearns, 2016). The composition of fuel sources for these countries are similar but are not exactly the same. A more plausible reason why the energy dynamics of these countries are similar may be that these three nations have consistently been the most developed, socially and economically, out of all the nations analysed. China and Japan do have economies larger than that of the UK and Germany, but this has only occurred in recent times. The fact that the UK, USA and Germany have consistently been global powerhouses may have influenced the energy mix of these three nations as well as how their society now reacts towards a change in ECS.

4.2.9. Brazil

Figure 4.17 shows that the ECS of Brazil moves within a very small range – only moving between 5%-8% until the second ECS peak occurs in 2008. The second peak is also higher than the first peak, with an ECS value eclipsing the 10% mark. In many ways, the shape of the ECS graph is similar to that of the Mexico. The only difference being that average ECS value of Brazil for the period is about 2% higher. When looking at the GDP and GNI per capita change of the country for the period, it can be seen to be very turbulent. There are also large disparities between GNI per capita and GDP change. These are characteristic of a developing country. There is a lot of potential to grow in these countries, but many social issues need to be addressed for this growth to be distributed equally. Following the two periods of high ECS, commonly seen in all countries, there are years of poor economic and social development, with the first recession in the early 1980's being worse than that of the one in 2008. Brazil also suffers from an aftershock recessions post 1980 and 2008, as seen in the Mediterranean nations and the USA. More data from this time period would provide us more details into the direction of the ECS line, but a lack of quality data is an issue.

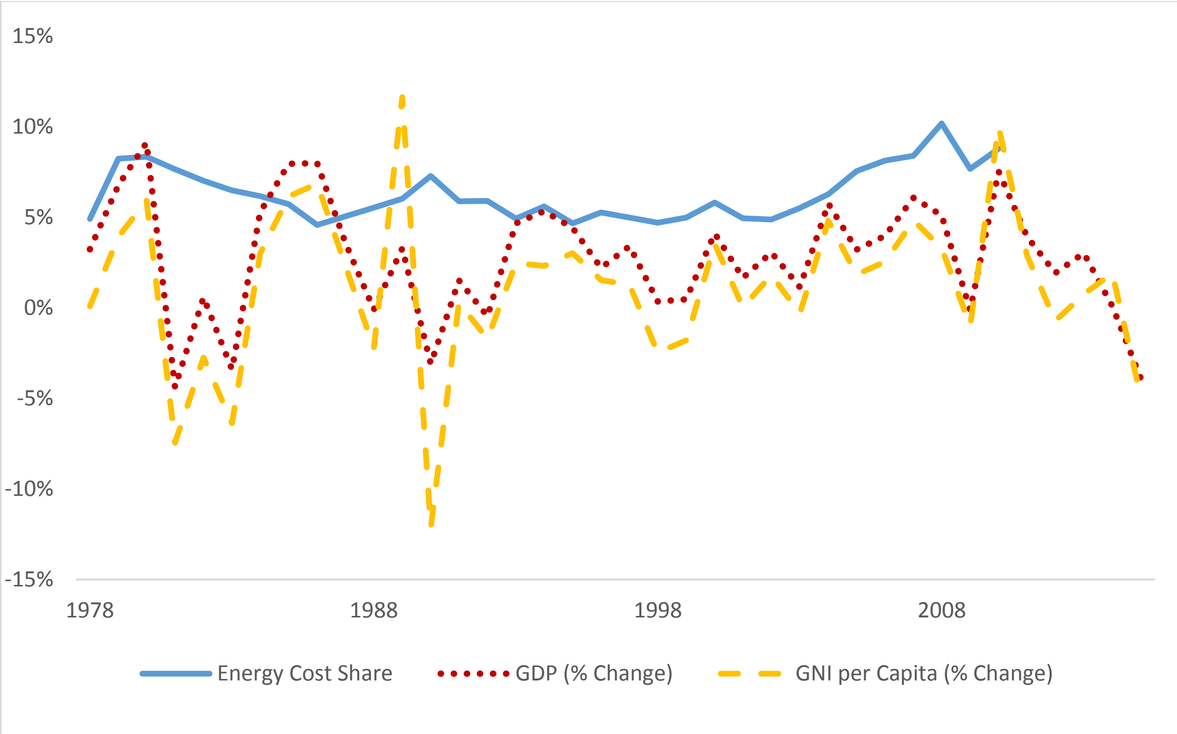

Figure 4.17: ECS, GDP and GNI per Capita Change – Brazil

Both the health and education indices of the nation, seen in Figure 4.18 grow steadily over the time period analysed. These values, as expected with a developing country, are slightly lower than the first world nations. Plotting the ECS against the health and education indices for Brazil clearly shows that these two indices are not affected by the change in energy expenditure.

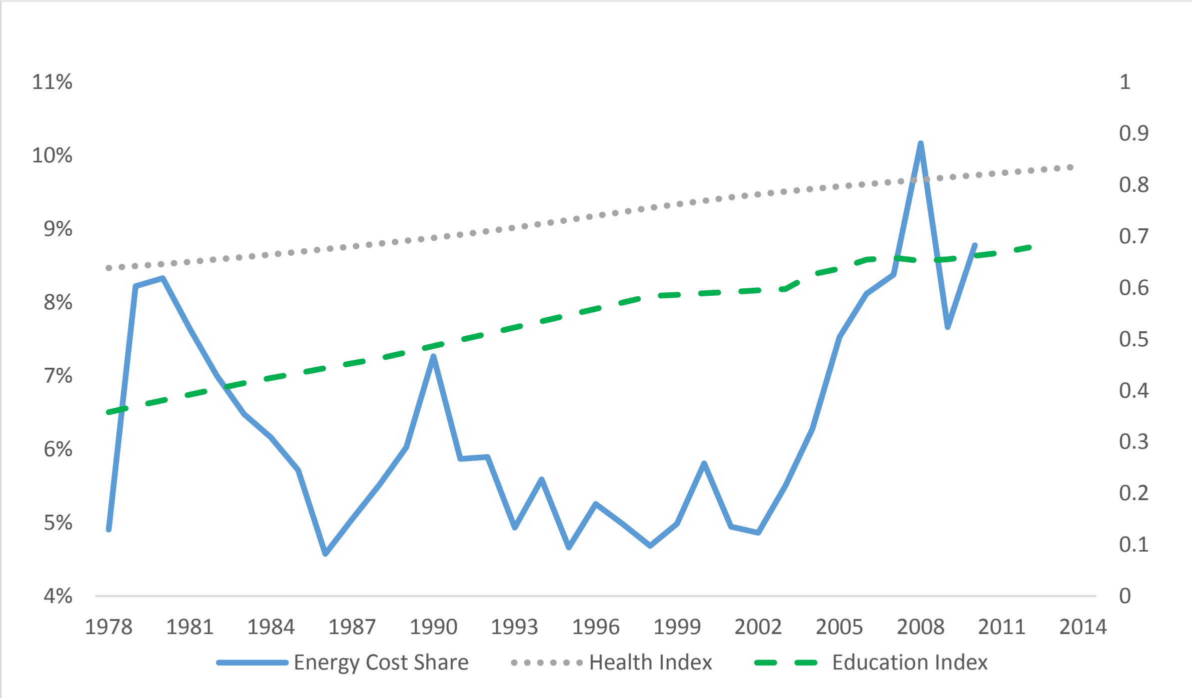

Figure 4.18: ECS, Health and Education Indices - Brazil

When analysing the results from the overall correlation test between ECS and GDP change, seen in Table 4.17, very little correlation could be identified. The results of these values also had high levels of uncertainty. It is interesting to note that Brazil, similar to that of Spain, established its lowest overall correlation after no lag between ECS and GDP change. The high levels of uncertainty are expected when looking at Figure 4.17 where the ECS values, as fluid as they are, seem relatively stable compared to the GDP change figures, The same argument can be made for the ECS and GNI per capita change. These results do not suggest that energy does not play a role in economic and social change, rather other political disturbances have had more of an effect.

Table 4.17: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Brazil

Year lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.131	0.468	0.079	0.664
1	-0.029	0.874	-0.030	0.870
2	-0.066	0.715	-0.032	0.861
3	0.167	0.353	0.084	0.641

As the results for the overall correlation coefficient, although statistically insignificant, were very similar for a one and two year lag, both of these were considered when performing the ECS threshold test. These results can be found in Table 4.18 below. Significant results were obtained over the first peak in ECS from 1978-1982. Strong, negative correlations were found between the ECS and GDP change, as well as ECS and GNI per capita change, for a two year lag. Like most developing countries, Brazil relies heavily on investments for the "Global North" for foreign investments in order to grow. As the increase in ECS over this period affected these first world nations, foreign direct investment (FDI) has decreased towards BRICs nations (Unctad, 2017). This may be a reason why Brazil, along with Italy and Spain, experience this two year lag. Negative correlations were also established between ECS, GDP and GNI per capita change for the period of 2004-2010, however, these results were statistically insignificant. The threshold established for these two periods also change very little between the two time periods.

Table 4.18: ECS threshold test results – Brazil

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1982	**-0.898**	**0.038**	**-0.884**	**0.047**	**6.5% (Two year lag)**
2004-2010	-0.435	0.388	-0.391	0.444	6.3% (One year lag)

Although similarities are seen when comparing the results from Brazil to those of the Mediterranean countries, there is quite a big difference in how Brazil obtains its energy. Renewable energy, predominantly hydroelectric power, makes up more than a third of the nation's energy consumption throughout the time period analysed (BP, 2014). Gas consumption, starting from the late 1980's, has played a minor role in comparison to other sources and in 2013 contributed only 11% of the overall energy mix (BP, 2014). Brazil is one of the few places in the world where biofuels have seen widespread success, and significantly supplements the energy needed to fuel the transport industry. Even so, Brazil has, and still does, rely heavily on oil for its energy production, more than 44% in 2013 (BP, 2014). The country does produce a significant amount of oil itself but is still a net importer. The fact that Brazil produces a large amount of oil may make the country less sensitive to oil price spikes, but does not shield it from overall oil price increases due to declining EROI values. Costs to produce oil continue to increase with further exploration into the ultra-deep water and sub-salt fields directly impacting the consumers of the oil, who are the people of Brazil. Furthermore, as reserves begin to dwindle, Brazil will have to look towards other nations for its oil supply, increasing imports. This makes Brazil even more dependent on the cost of oil. Brazil's economy was built on the back of its oil production, but unless it drastically changes its sources of fuel, it could experience massive turbulence in the years to come. One could argue that the country’s hydro-power should provide some resilience to its energy supply, but that is not necessarily the case. Major water shortages in 2012 and 2013 crippled electricity production, making it even more reliant on fossil fuels for energy. Although difficult to determine, these droughts could be linked to climate change, making Brazil even more vulnerable in the future.

4.2.10. China

At first glance of the ECS graph of China, shown in Figure 4.19, the extremely high peak in 1979 is glaringly obvious. Much like other nations in Asia, China experienced extremely high growth rates from the beginning of the 1960's. This growth rate was driven by exports that could be manufactured inexpensively, due to cheap labour. High energy consumption was needed to support this rapid growth. It has been postulated that the high growth rates achieved by these Asian nations, linked with oil consumption, drove up demand and, in turn, a price of oil. During this first peak in ECS, categorised by high oil prices, China was effectively a net exporter of oil. This, as well as the extremely low wage rate for employees, could have allowed China to not be severely affected by the price increase. There is a slight dip in GDP and GNI per capita change following this extremely high peak, however, the economy still manages to grow at around 5%. These high growth rates continue throughout the period being analysed. Economic and social change seems to have little correlation to energy expenditure. GDP and GNI per capita change do slow in 1991 and again in 2008 (both time periods have high ECS values). On both occasions, however, these two indices stay well above the recession mark.

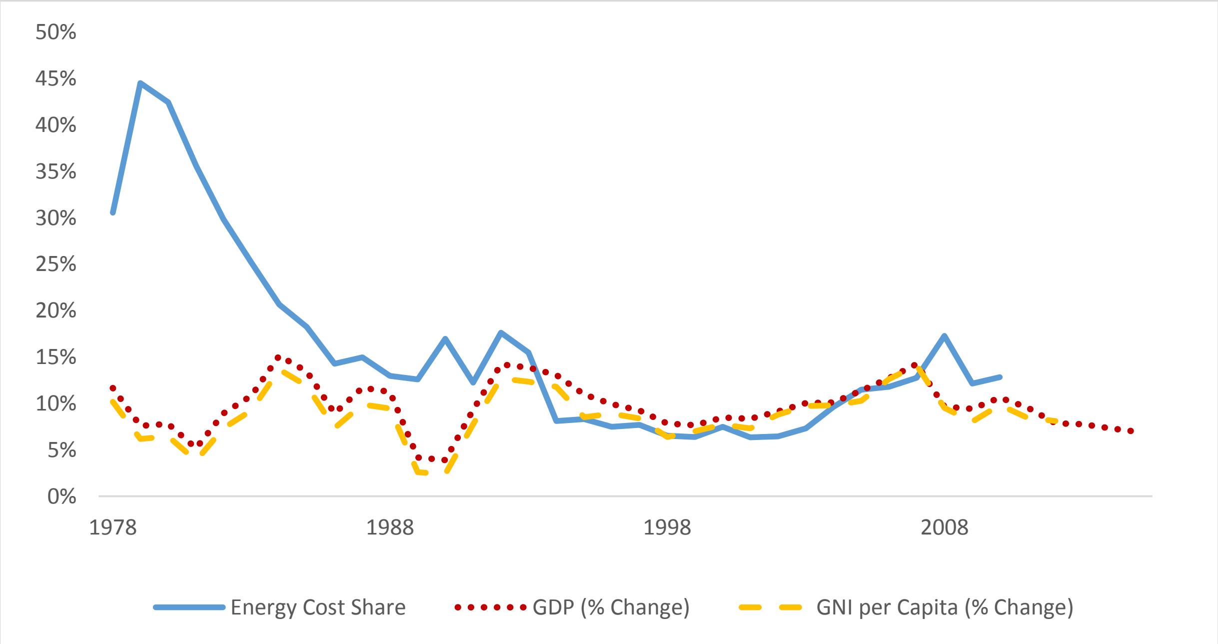

Figure 4.19: ECS, GDP and GNI per Capita Change - China

The Chinese economy is predominantly powered by coal, contributing more than two-thirds of primary energy supplied in 2012 (Mearns, 2015). An acceleration in consumption, especially in coal, come in 2001, the beginning of the 10th 5-year plan. As China has vast amounts of coal supplies, this fuel has come very cheaply and has become the backbone of the country's growth. Although this dependency on coal has fuelled the nation to great heights, the country is now extremely vulnerable to any carbon taxing initiatives that may commence due to climate change. A decrease in coal consumption is visible from 2010 onwards, the beginning of the 12th 5-year plan, with its losses being made up by hydropower (Mearns, 2015). Investments into nuclear power have also been made, however, the country is still very much dependent on coal for energy and could be for the distant future. China's oil production could not keep up with its economic growth, surrendering its oil exporter status in the 1990's (Mearns, 2015). It is now reliant on oil imports to fuel its transport sector, making it susceptible to major economic and social effects if energy price fluctuations occur. Through an energy resilience lens, it seems as if China has become a victim of its own success.

Figure 4.20 shows that there is very little correlation between the ECS of China and the two human development indices, health and education. Most notably in the graph, there is a big discrepancy between the health index and education index throughout the time period analysed. As discussed in Section 3.6, the HDI takes a very "westernised" view of development. Large portions of the population, especially in rural areas, may not receive a formal education that can be monitored by the UN. These kids may be trained to one-day take over a family farm and are equipped with the correct skills they need to survive. This may seem like a shame, but a shift to a simpler, less consumer driven lifestyle led by many of these people, is seen by environmental ecologists as the way society needs to move in order to counteract global warming. To move forward we may need to take the proverbial step back.

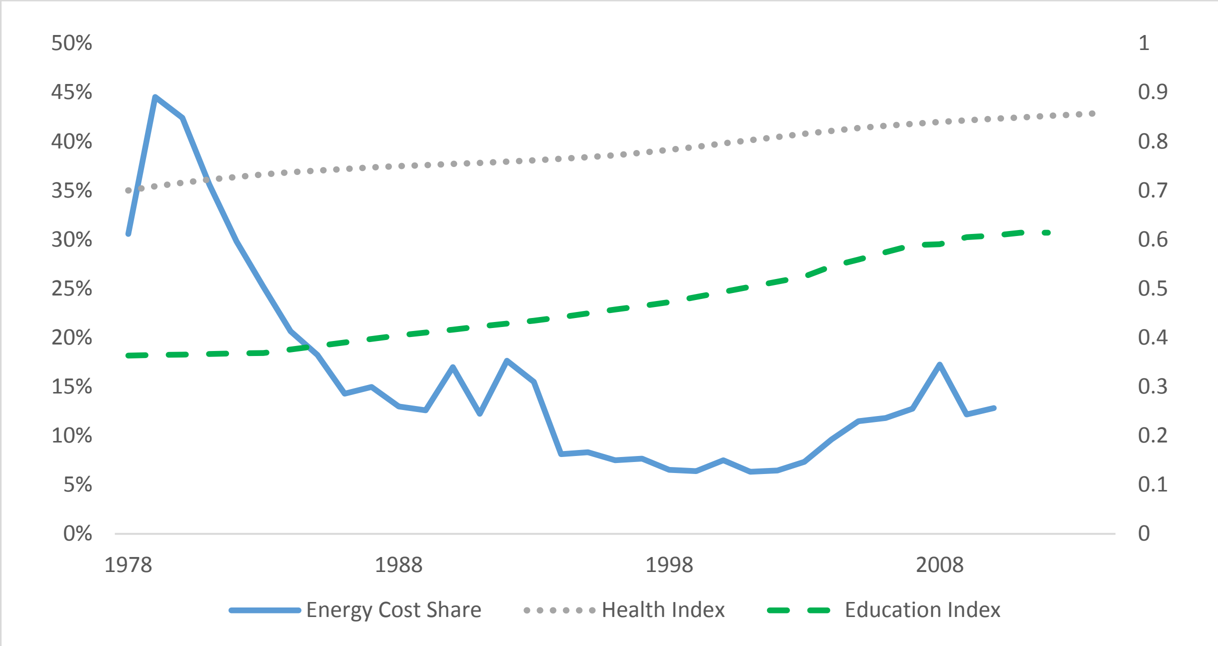

Figure 4.20: ECS, Health and Education Indices - China

As there was still some response to ECS shifts from GDP and GNI per capita change, correlation tests were still conducted. Table 4.19 shows the results for the overall correlation between ECS and the two metrics. Understandably there is a very weak correlation between the ECS and economic change. The same can be said for ECS and GNI per capita change. This consolidates the conclusions drawn from the graph. It is worth noting that the strongest negative correlations were in fact established for a zero lag, for both GDP and GNI per capita change, contrary to most other countries.

Table 4.19: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - China

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.146	0.417	-0.201	0.263
1	-0.129	0.473	-0.198	0.2681
2	-0.018	0.919	-0.113	0.531
3	0.111	0.537	-0.004	0.980

When conducting the ECS threshold test, the results of which are in Table 4.20, it was established that there was an ECS threshold for the period of 1978-1983, beyond which the economy does not perform well. In saying that, the economy still grows at a high rate in comparison to global growth. Conditions in China, as well as the globe, have changed drastically since these times and not much can be read from this threshold.

Table 4.20: ECS threshold test results – China

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1983	**-0.842**	**0.018**	**-0.836**	**0.019**	**25.2% (One Year Lag)**
2005-2010	-0.584	0.223	0.658	0.156	12.6% (One Year Lag)

China seems to be a bit of an anomaly in many ways. The extremely high ECS threshold had little effect on the country's booming economic growth in the late 1970's. The main reason for this has been postulated that the country was able to produce its own fuel at the time. This identifies a gap in the in the methodology used. As the energy expenditure is calculated using consumption of the fuel source, as well as the price. The fact that China was able to produce its own oil should reflect in the price. However, due to data unavailability, all countries without oil price data were assumed the average annual Brent oil price (see Appendix A). Very little price data was available from China before 1990. Of course this year marked the collapse of the Soviet Union and, ideologically, communism. Most of the price assumptions for coal and oil were made using the price available for India. This may have been flawed. It is therefore crucial to delve into a countries energy mix, as well as its energy market stand point, in order to gain any real insight in the data. Secondly, the country has traditionally had a planned economy, with a central party allocating resources such as labour, capital and energy. This is in contrast to many of the other countries being analysed, where price and consumption is dependent on the market. By controlling energy prices and consumption, the Chinese economy may have been sheltered from high global energy prices and the effects of high ECS.

4.2.11. India

The effect of ECS on GDP and GNI per capita change seems to be slightly different with India than most of the other countries analysed. Looking at Figure 4.21, one can see that high ECS peaks seem to have an immediate reaction to economic and social growth. India’s economy may be very responsive to high ECS values, similar to situation seen in Brazil, China and Spain, as GDP and GNI per capita change reacts immediately. This is then followed by a recovery by these two metrics and then a period of low performance. Further opposing the theory, periods of high economic change can be seen when the ECS value is low. There is also a general tendency for economic growth to be much higher than social growth throughout the period being analysed. Much like China, India has an extremely low wage rate (World Bank, 2016). This coupled with the high use of biomass for energy, which is not taken into account in this study, means that the country is able to withstand much higher energy expenditure than most. An average ECS value of 7.5% is more than double that of the Mediterranean countries. As pressure for social investment increases, on top of dwindling biomass resources, the economy could be at risk should this high average ECS value not decrease.

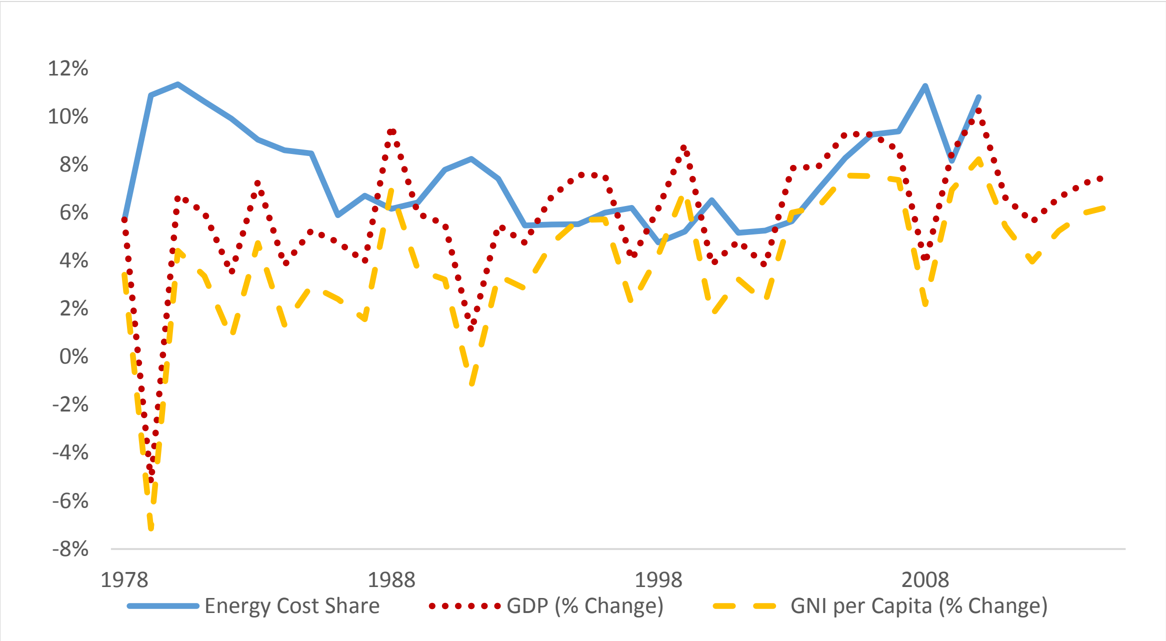

Figure 4.21: ECS, GDP and GNI per Capita Change - India

Figure 4.22 shows that the health and education index of India grows fairly constantly over the period being analysed. This is contrasting to the turbulent ECS value. It can be said that these two indices have very little correlation to energy expenditure. It must also be noted that national income levels are also extremely low in India and that omitting this index in favour of the GNI per capita change may allude to the fact that India has a relatively high social development. This, however, is not the case as India is ranked 131st of the UN's Human Development report (UNDP, 2015). GNI per capita sits at $5 663 (World Bank, 2016).

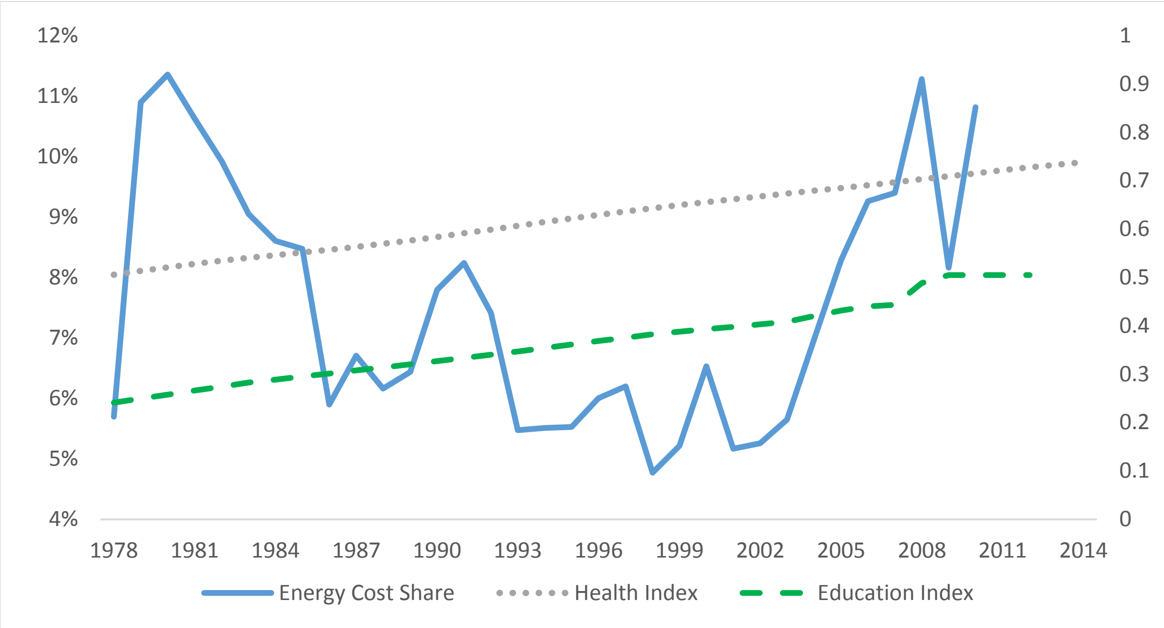

Figure 4.22: ECS, Health and Education Indices - India

Taking into account the immediate reactions seen of India's economic and social change to ECS changes, a zero year lag was included for this country. As we can see in Table 4.21, this lag produced the strongest negative correlation for both GDP and GNI per capita change, confirming the observations of Figure 4.21. The correlations also seem to become positive after a one year lag, due to the rebound in the economy, followed by negative correlations two and three years later. These overall correlation results were seen to be statistically insignificant. This could be to the turbulent nature of economic and social change characteristic of many third world nations.

Table 4.21: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - India

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.160	0.374	-0.178	0.321
1	0.075	0.676	0.074	0.683
2	-0.084	0.643	-0.124	0.492
3	-0.031	0.866	-0.062	0.731

The unusual nature in which the economy and societal development indicators reacted to ECS were also considered when conducting the ECS threshold test, the results can be seen in Table 4.22 it was noted that a two year lag produced a stronger, negative correlation for the first high ECS peak. A zero year lag was then seen to produce a stronger, negative correlation from 2005-2010. The results of these were seen to be statistically insignificant, however. Similar to the conclusions drawn from Figure 4.21, is that GNI per capita is more severely affected by this rise in energy expenditure. Furthermore, the estimated ECS threshold was seen to decrease from the first period to the second.

Table 4.22: ECS threshold test results – India

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1983	-0.313	0.545	-0.326	0.528	9.1% (Zero Lag)
2005-2010	-0.431	0.395	-0.493	0.320	8.3% (Zero Lag)

Although no significant results were obtained when analysing India, an interesting trend was found about this country. The results confirm that India's economy and society, similar to that of Brazil, China and Spain, immediately reacted to a high ECS values. After an initial recovery the following year, an aftershock generally followed. The fact that India reacts so suddenly to an increase in energy expenditure, as well as its high dependence on imports, makes it extremely vulnerable price spikes in the energy market. Nations with a one or two year lag could brace for the effects and put certain measures in place to soften the blow. India does not have this luxury. The aftershock, as discussed above in other countries above, is also a worrying circumstance as there is no period of sustained growth after the price spike, often seen as essential for offshore investments.

Looking at India's energy mix over the period, it is seen to be very similar to China's. Oil has contributed around 30% of India's energy supply throughout the period with coal providing the majority of the energy. Contrastingly to China, India has always relied on oil imports (Tverberg, 2016). This may be why India was affected more by the oil shock in 1979 than China. Furthermore, India's coal consumption rate has recently surpassed its production rate, making India one of the largest coal Importers in the world (Tverberg, 2016). This may prove costly in the face of rising commodity prices due to scarcities. It seems as if India has also been a victim of its own successful growth in the last 50 years. A decrease in coal consumption has occurred in recent years, with the slack being picked up by natural gas and renewables. If these efforts are enough to avoid calamities remains to be seen (Tverberg, 2016).

4.2.12. Russia

From Figure 4.23 it can be seen that Russia, much like China, has an exceptionally high ECS peak in 1980, a value of around 30%. The ECS then follows a similar pattern to many of the western nations as it decreases throughout the rest of the time series until 2002. At this point, it begins it’s ascent toward a much smaller peak in 2009. At the time of the first peak, oil and natural gas contributed most to Russia's energy consumption, which the nation was able to produce itself. Similar to the case of China, it was difficult to obtain price data for Russia before 1991. The assumptions made in the methodology may have inflated this ECS peak somewhat. Unlike any of the other nations in this study, Russia showed almost no correlation to this spike in energy expenditure. This could be explained by two reasons. Firstly, Russia's energy independence could have protected the country from high commodity prices. Secondly, the political principles of the time may have isolated Russia from the rest of the world. Planned economy principles used by the Soviet Union may have sheltered Russia from the global economic recession in the late 1970’s, similar to that of China. In the 1990’s Russia began to transition toward a market economy, becoming more vulnerable to global markets. Experiencing high ECS values in 2009 may have caused GDP and GNI per capita change figures to drop, something that did not happen previously in the late 1970's.

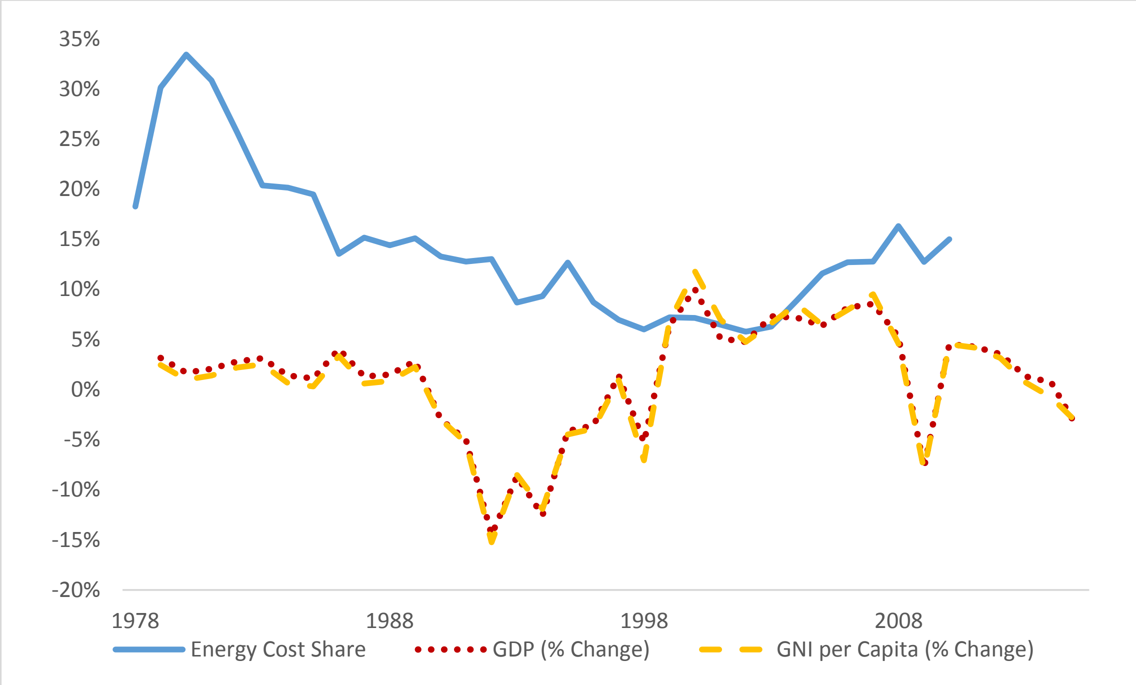

Figure 4.23: ECS, GDP and GNI per Capita Change - Russia

Further analyses of Figure 4.23 shows that very low GDP and GNI per capita change rates occurred pre 1989. A period of recession then occurs for almost eight years, after which growth rates rise. The second ECS peak in 2008 seems to have an effect on economic and social conditions. Russia's entire economic and social development patterns are heavily influenced by its communistic principles:

- The very low growth rates of the 1980's, where most countries experienced periods of rapid, even if intermittent, development.
- The contraction of the economy in 1990 can be attributed to the collapse of the Soviet Union. It is interesting to note that ECS was relatively unaffected during this contraction of the economy. This indicates that energy expenditure and GDP decreased in a proportional manner.
- The way in which economic and social development are remarkably linked throughout the period could also be characteristic of the nation's political ideals.

- The data itself is affected by communism. It is very difficult to obtain any price data for the Soviet Union.

Looking at Figure 4.24, the health index of Russia has a very unusual shape in comparison to other countries in this study. The index does not see a gradual increase throughout the period, rather it oscillates between 0.7 and 0.75, very high for a developing country. Gradual growth is then noticed from 2004 onwards. This anomaly could be due to the difficulty in obtaining accurate data from this country, as mentioned above. The education index sees steady growth over the period. Although similarities can be drawn between the ECS value and health index, these correlations would contradict all other patterns seen in this study. This analysis was seen to be coincidental and should not be further due to the very degree of accuracy in the data. No correlations were established between these indices and the ECS.

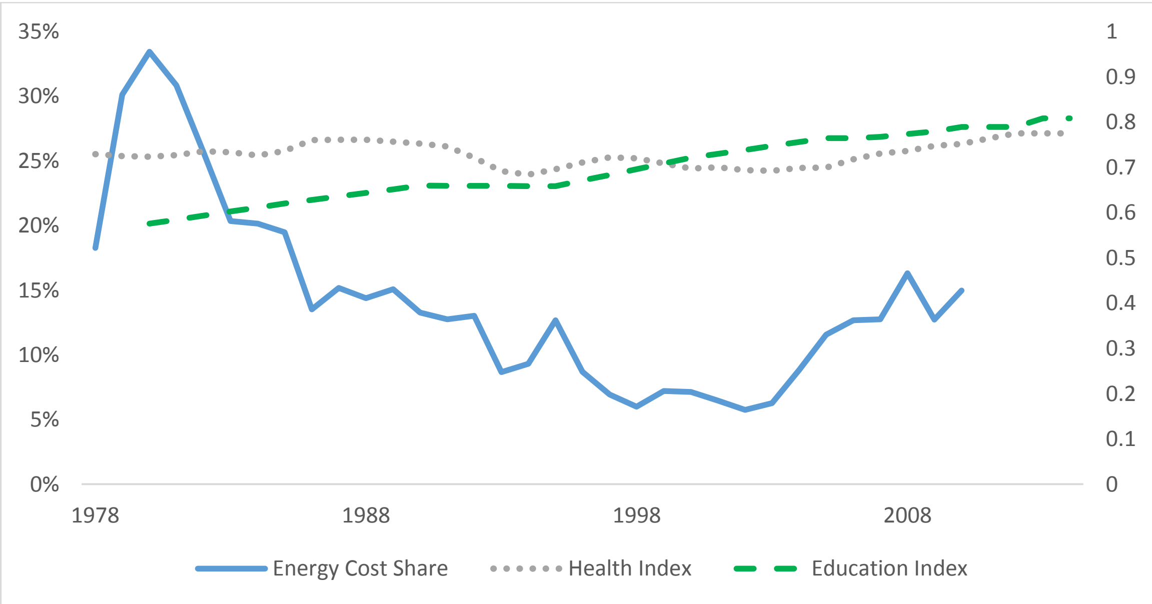

Figure 4.24: ECS, Health and Education Indices - Russia

An overall correlation test between the ECS, GDP and GNI per capita change was conducted. Shown in Table 4.23, the results indicate no real correlation between ECS and GDP change when the analysis is conducted over the entire time period. This is evident in Figure 4.25 as no real reaction to the ECS from 1978 to around 2007. The same conclusion can be drawn for GNI per capita change.

Table 4.23: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Russia

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	0.054	0.770	0.002	0.992
1	-0.038	0.833	-0.088	0.626
2	-0.086	0.635	-0.134	0.447
3	-0.169	0.347	-0.222	0.214

An ECS threshold test was conducted for the second ECS peak beginning in 2005. A threshold test for the first peak was omitted as it can be seen in Figure 4.23 that there is very little variation in GDP and GNI per capita change over the period during and after it occurred. Table 4.24 shows that there is a strong, negative correlation between GDP change and ECS for this time period. A similar result was established for GNI per capita change and ECS. An estimated ECS threshold of 11.6% was found, exceptionally high in comparison to other countries. This can be put down to the excessive energy intensity levels at which the Russian economy operates.

Table 4.24: ECS threshold test results – Russia

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
2005-2010	**-0.866**	**0.026**	**-0.860**	**0.028**	**11.6% (One year lag)**

When delving into the country’s energy mix, it seems as if Russia is in a fairly secure position. Oil, Natural gas and coal contribute most of the energy being consumed, all of which are in abundance in Russia. The country's economic growth is now driven by energy exports, given its high oil and natural gas production. Oil and natural gas revenues accounted for 50% of Russia's federal budget revenues and 68% of total exports in 2013 (Trading Economics, 2017). Price increases due to higher EROI values could lead to falling demand, thus threatening a major component of the Russian economy. The abundance of natural resources has allowed the nation to develop inefficient mechanisms to grow. The country has a tremendously high energy intensity level (a measure of the amount of energy needed to grow the economy by 1 US dollar), likely due to vast amounts of resources cheaply available. This has effects on global warming. Russia is one of the leading CO_2 per capita emitters, along with China and the USA (UCSASA, 2014) . Any global carbon taxing initiative could damage the state of the economy and have impacts on society.

4.2.13. South Africa

The last of the BRICS nations to be analysed is the only nation from the African continent. Looking at the ECS shape of South Africa over the time period, shown in Figure 4.25, we see that the first ECS peak in 1979 eclipses the 6% mark. The ECS then decreases gradually until 1985. The ECS then settles in between 2 and 3% before rising to a second ECS peak in 2009. Much like Brazil and Mexico, the second ECS peak is notable higher than that of the first. The GDP and GNI per capita change figures over the time series suggest that the country has a turbulent economic history. The GDP change seems to oscillate between 6% and -2%. There is also a large disparity between GDP and GNI per capita change throughout the series, with GDP having a 2% higher average growth rate than GNI per capita. The Apartheid regime, in which citizens were racially segregated and discriminated, could be pinpointed as a leading cause for much of this volatility. By refraining from providing a majority of the public, and workforce, with adequate education and basic services, the economy faced many difficulties in expanding due to a deficiency of skilled labour. From a social perspective, many South Africans were forced into low paid jobs, thus entrenching most of the population in a life of poor living conditions. This is reflected in the substantially low GNI per capita change rates. Even though apartheid ended in 1994, the effects of the 50 year regime are still seen in the country today, as GDP and GNI per capita change are still significantly separated on the graph long after 1991. Two years after the 1979 ECS peak the country experiences a significant period of economic and social recession. This is followed by a recovery year and an aftershock recession. There are two other periods of poor economic and social growth during the period of stable ECS. After the second ECS in 2009, the country experiences a sharp decline in social and economic standards.

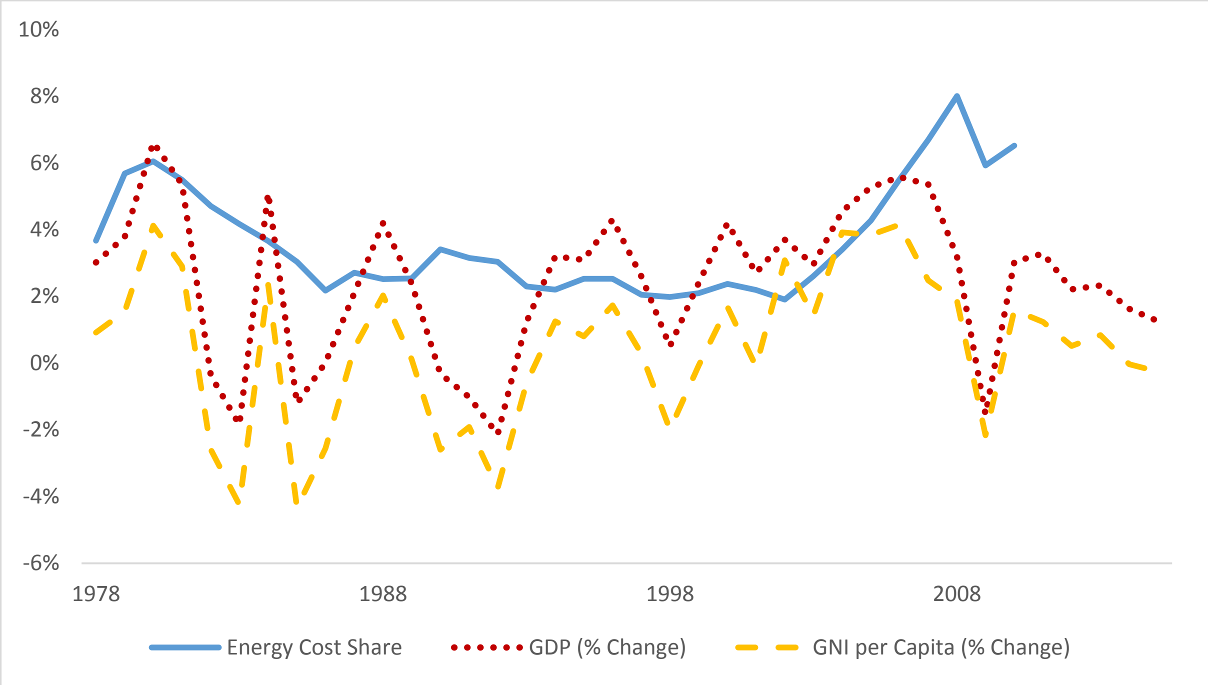

Figure 4.25: ECS, GDP and GNI per Capita Change – South Africa

South Africa is one of the top 10 producers of coal in the world (World Atlas, 2016). It is no surprise then that this fuel source provides the lion's share of primary energy, almost 70% (Fisher & Downes, 2015). With abundant stocks and cheap labour, the country has used this to provide cheap electricity to industry. This trend is seen with most of the BRICS nations. The average ECS value, in contrast to these other nations, is much lower than that of China, Russia and India. In fact, these ECS values seem to be on a scale similar to those of the European and North American countries. This may be due to the dynamics in which the society was, and still is, separated.

Looking at Figure 4.26 we see that the education index rises throughout the period, with an acceleration coming from 1984-1993. The health index begins increasing, but then takes a downward turn in 1990. It then decreases until 2005 before beginning to peak again. This dip in health could be due to the HIV epidemic that was extremely prevalent in the country during that period (Department of Health South Africa, 2012). As can be seen in the graph, there is no correlation between the ECS of the country and these two indices.

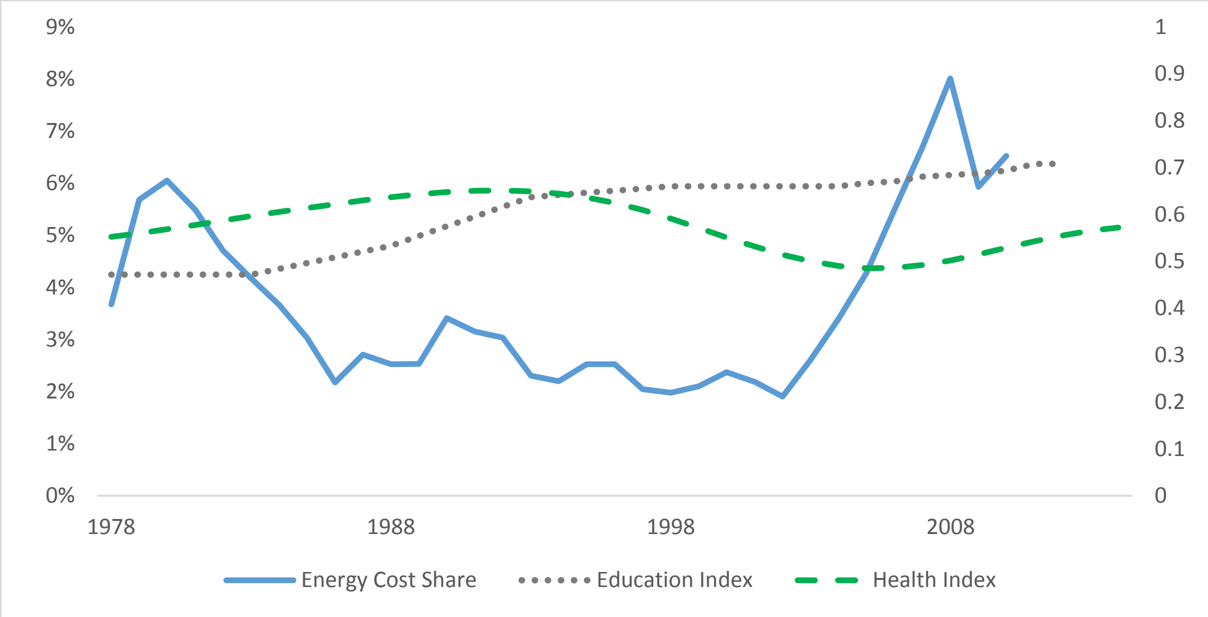

Figure 4.26: ECS, Health and Education Indices – South Africa

The results of the overall correlation tests are shown in Table 4.25. Very little correlation was seen for ECS and GDP change for a one year lag, however, the correlation did increase when moving toward a three year lag. Similar correlation coefficients were established for ECS and GNI per capita change. All of the overall results were seen to be statistically insignificant. This could be due to the rapid movements of GDP and GNI per capita change, especially when the ECS value remained relatively stable. It can be posited with confidence that political instability in the nation has defined the country's economic and social history, for this time period, more so than energy expenditure.

Table 4.25: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags – South Africa

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	0.194	0.230	0.269	0.130
1	0.005	0.975	-0.043	0.810
2	-0.168	0.350	-0.141	0.433
3	-0.218	0.222	-0.212	0.236

Considering the trends seen in the overall correlation test an ECS threshold test was conducted, with the results displayed in Table 4.26. A negative correlation was obtained between ECS and GDP change, as well as ECS and GNI per capita change, for the period of 1978-1983. This was established using 4.2% threshold with a two year lag. The results were seen to be statistically insignificant. The results for the second time period analysed were seen to be statistically significant and provide very interesting. There is a remarkably strong, negative correlation between ECS and GDP change. This correlation is even stronger when comparing ECS and GNI per capita change figures, with a correlation coefficient of -0.923.. These correlations are extremely strong, especially when one considers that a large amount of energy in the country usage is biomass, which is not taken into account in this study. If reliable data on this matter could be found, it would likely show that a stronger correlation is found between ECS and societal development. The thresholds established are also interesting. Firstly the smaller threshold established for the second time period was able to yield a stronger negative correlation coefficient. This suggests that the country has become more dependent on energy over the time period. Secondly, the thresholds established are very low and are similar to those of the Mediterranean nations. This is contrary to other BRICS nations, such as India, China and Russia, which have also built their economies on the back of locally produced coal.

Table 4.26: ECS threshold test results – South Africa

Years	**GDP Change**		**GNI per Capita Change**		**Estimated ECS Threshold**
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1983	-0.362	0.480	-0.305	0.556	4.2% (Two year lag)
2004-2010	**-0.855**	**0.014**	**-0.923**	**0.003**	**3.4% (One year lag)**

As mentioned early, the Apartheid government may have had a role to play in these results. In essence, the government may have split the nation into two. With one part of the society controlling most the wealth, establishing an economy similar to the dynamics of a European country. The majority of society was tasked with providing cheap labour in order for big business to succeed. The results of this can be seen in Figure 4.25 as the ECS values are similar to many European nations, while the GDP and GNI per capita change figures are characteristic of third world nation. Furthermore, many of South Africa's poor use biofuel for their energy needs. By excluding biofuels this study focusses more on the nation's wealthy residential and business sector.

From an energy perspective, it seems that a society has been built upon very cheap energy, electricity in particular, due to the cheap labour and abundant coal supplies. Furthermore, the economy is unwilling to absorb higher energy costs and would rather decrease expenditure, be it in the form of decreasing infrastructure or reducing its work force. The country could avoid intermittent growth patterns due to energy costs by using energy sources, particularly electricity sources, which can supply energy at relatively constant prices.

Prices of coal-generated electricity have dramatically increased, and will continue to. This could be due to poor governance, declining quality of coal as well as the labour force is demanding better working conditions and high salaries, and rightly so. Climate change initiatives, in the form of carbon trading or taxing, could further increase the price of energy in the country.

4.2.14. Australia

The shape of Australia's ECS curve, seen in Figure 4.27, is similar to that of the other first world nations being analysed. The ECS is high at first, before decreasing over time towards the 2-3% mark. It then remains around this level until around 2002, where it starts to rise towards a second spike. There is a difference that sticks out however. Generally, countries experience a high energy expenditure for one or two years around 1980, leading to the commonly used term of 'ECS peak'. The ECS value for Australia, at this same time, seems to rise above 6% and then maintain this for up to four years. One would think that this plateau of high ECS would cause considerable damage to the economy and society. The GDP and GNI per capita change figures, however, seem to maintain meaningful levels of growth for this time. A sharp drop in these figures eventually occurs in 1983, before they recover again the following year. The nation is also not terribly affected by the second ECS peak seen in 2009, not on the scales felt by the rest of the globe at least. The economy experiences its only other recession in 1991 where energy expenditure is relatively stable. There is a noticeable gap between the GDP and GNI per capita change lines throughout the time period, suggesting that the economy grows at a faster pace than society.

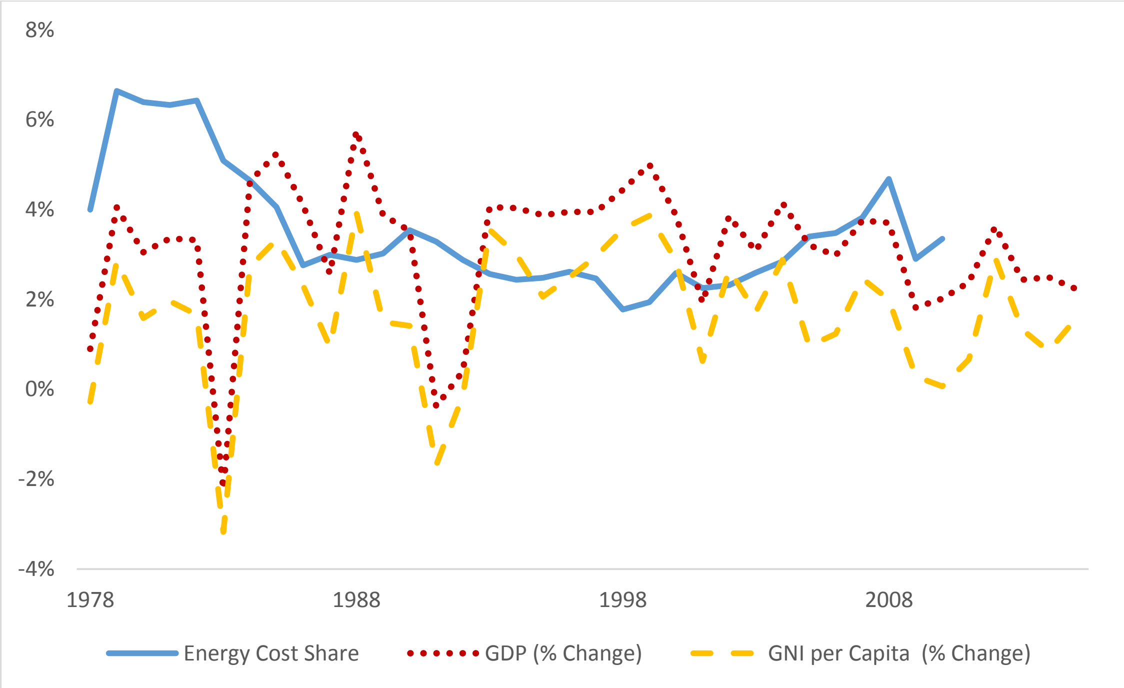

Figure 4.27: ECS, GDP and GNI per Capita Change - Australia

Although the country seems to be resilient to high energy prices, Figure 4.27 shows that growth figures are much higher during periods of low ECS. Once energy expenditure levels come down from their initial high levels in the early 1980's, the growth rate begins to climb. High growth rates between 1993 and 1999 are also seen during periods of low ECS values. Australia provides an exception to the proposition made by Bashmakov (2007) as growth is not correlated to an upper threshold, rather a lower one. Evidence of this also occurred in Spain, Italy and India, however, the effect is more apparent in Australia. Instead of a strong correlation as an upper threshold of energy expenditure is breached, development may have a stronger correlation once a lower threshold is crossed. Although these may seem similar, they are very different.

Looking at the health and education indices of Australia from 1978-2014, shown in Figure 4.28, it can be seen that these values are tremendously high. The country has the second highest HDI in the world, with only Norway being higher. The health index seems to gradually increase throughout the period, reaching an exceptionally high value of 0.95, indicating that almost all of the population reaches an age of 85. It obviously is unaffected by the turbulent ECS value. The education index has a very odd shape to it, being very "square" in nature. This could be due to the method in which the HDI data was collected and used to generate the graph. Before 2005, mean and expected years of schooling data was only monitored every 5 years. The values in between these points were interpolated. An increase in expected years of schooling occurred between 1990 and 1995, causing the sudden increase. After 2005, this value slightly decreased while the mean years of schooling increased, causing the education index to rise to almost perfect levels. At first glance, one could draw comparisons between the ECS and education index. When delving into data used to generate the graph, however, it can be said there is very little correlation between these two.

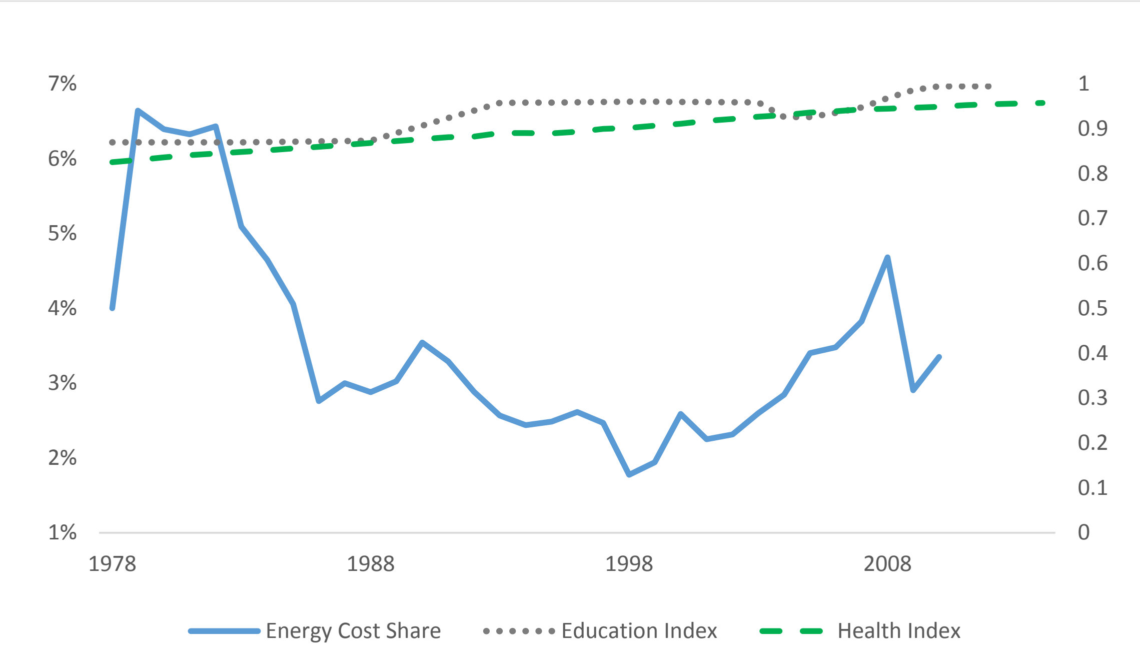

Figure 4.28: ECS, Health and Education Indices - Australia

The results from the overall correlation test can be seen in Table 4.27. A statistically significant correlation was found between ECS and GDP change when a one year lag was applied. The negative correlation coefficient of -0.304 indicates that ECS and growth in the economy are indirectly proportional. An even stronger, negative correlation was found between ECS and GNI per capita change for the same time lag.

This shows that energy expenditure for this region has a greater correlation to social growth than economic growth. This could be assumed by the disparity between GDP and GNI per capita change seen in Figure 4.27. Negative correlations between these indices and ECS were established when applying two and three year lags. The results, however, were seen to be statistically insignificant.

Table 4.27: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Australia

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.156	0.386	-0.208	0.245
1	**-0.304**	**0.086**	**-0.343**	**0.051**
2	-0.222	0.214	-0.273	0.125
3	-0.107	0.555	-0.179	0.318

A slightly different procedure was followed for the case of Australia when attempting to establish an ECS threshold. Using the periods of high ECS values, the Pearson's correlation test was used in an attempt to establish upper ECS thresholds, similar to other countries. As seen in the results in Table 4.28, negative correlations were established for the years between 1978 and 1984. These results were seen to be statistically insignificant. A very small correlation was also found for the period of the second ECS peak, from 2005-2010, but with a very high *P*-value rendering the correlation insignificant.

The fact that Australia could obtain an overall correlation but not one for high ECS values prompted further investigation. This scenario is unique to this country as the periods of high ECS generally create the correlation between the indices. During periods of high ECS, according to Bashmakov (2007), the economy is greatly dependent on energy expenditure. No other country in this analysis yielded an overall correlation without a significant ECS threshold being established. Considering the conclusions drawn from Figure 4.27, the periods of low ECS values were then used in order to obtain a lower ECS threshold. Using a period from 1990-2005, where a dip in ECS was seen, significant results were obtained. A negative correlation coefficient between ECS and GDP change was established at -0.681. Negative correlations of similar magnitude were found between ECS and GNI per capita change. A threshold value was obtained by using the highest ECS value for this period. These results indicate that when ECS dips below the 3.4% mark, GDP and GNI per capita change are correlated to energy expenditure. Spain, Italy and India exhibit similar traits to Australia by having high developments rates during periods of low ECS values. These countries, however, are more severely affected by high ECS values. Australia, on the other hand, seems to be fairly resilient to high ECS values and energy expenditure dictate the rate of growth when they are relatively low.

Table 4.28: ECS threshold test results – Australia

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1984	-0.544	0.207	-0.538	0.212	4% (One year lag)
1990-2005	**-0.681**	**0.004**	**-0.655**	**0.006**	**3.4% (One year lag)**
2005-2010	-0.14	0.788	-0.107	0.864	3.4% (One year lag)

Australia is fortunate enough to have large amounts of natural resource. On top of supplying coal for its own energy, the country is a major exporter of coal to the USA and, most significantly, Asian countries (Government of Australia, 2015). This could explain why the country thrives when energy expenditure is low. Demand for coal during these times has drastically increased in other countries, creating more exports for Australia. The results of this analysis may not reflect the direct effect ECS on the country, but rather how global trends of ECS have an effect on the economic and social development. Australia's coal exports, along with the fact that the country was able to produce its own oil at the time, may be why the economy was fairly resilient to the high oil prices seen in 1979. With oil and coal at hand, the country's economy is characterised around these two sources. Oil consumption surpassed production around the turn of the century, making Australia a net importer of oil and sensitive to oil prices. This is worrying as oil makes up almost a third of the country's energy mix (Lane, 2016). With a global recognition of the damages CO_2 emissions are having on the environment, nations are beginning to steer away from coal and rather pursue cleaner energy sources. This could have massive ramifications on Australia's oil exports. Locally, the country has come under scrutiny for its coal-based energy mix (Lane, 2016) and carbon trading mechanisms have been established.

4.2.15. New Zealand

The final country in the analysis is New Zealand. Looking at Figure 4.29, we can see that the ECS graph over the time series has a similar shape to that of South Africa and Mexico. A high ECS peak is seen of 6% is seen around 1980, after which it begins to decline. The ECS values oscillate between 3 and 4% until 2002, where it begins its ascent to the second peak. This second peak is also seen to be higher than the first, at over 7%. The reaction by the GDP and GNI per capita change figures to the first high ECS is unusual. Most countries in this analysis have declining GDP and GNI per capita change rates during the high ECS peak. In New Zealand's case, these indices have a very unstable pattern. From 1980-1984, economic and social development fluctuate between good and poor performance after each year. Following the period of the first ECS peak, an acceleration of growth is noted in other nations. This is contrary to other first world countries. A slowdown in GDP growth for most countries occurs in the years of 1993 and 2002, where New Zealand's economic growth accelerates. High growth is seen in 1991 and 1998 for other nations but not in the case for New Zealand. From 2002, the economy seems to react in a fairly normal manner to rising energy expenditure, except for the fact that the reaction by GDP and GNI per capita change to rising ECS happens instantly and not after a one year lag. When comparing GDP with GNI per capita change, it can be seen that society is often impacted more by declining fortunes in the country. The GNI per capita change graph is well below the GDP change graph from 1993-1998, 2002-2006 and again from 2013 onwards. An aftershock seems to impact GNI per capita change and not GDP change. Due to data unavailability, assumptions had to be made for the GNI per capita change figures of New Zealand from 1978-1990. The large downwards spike in this figure may be where the two data sets meet.

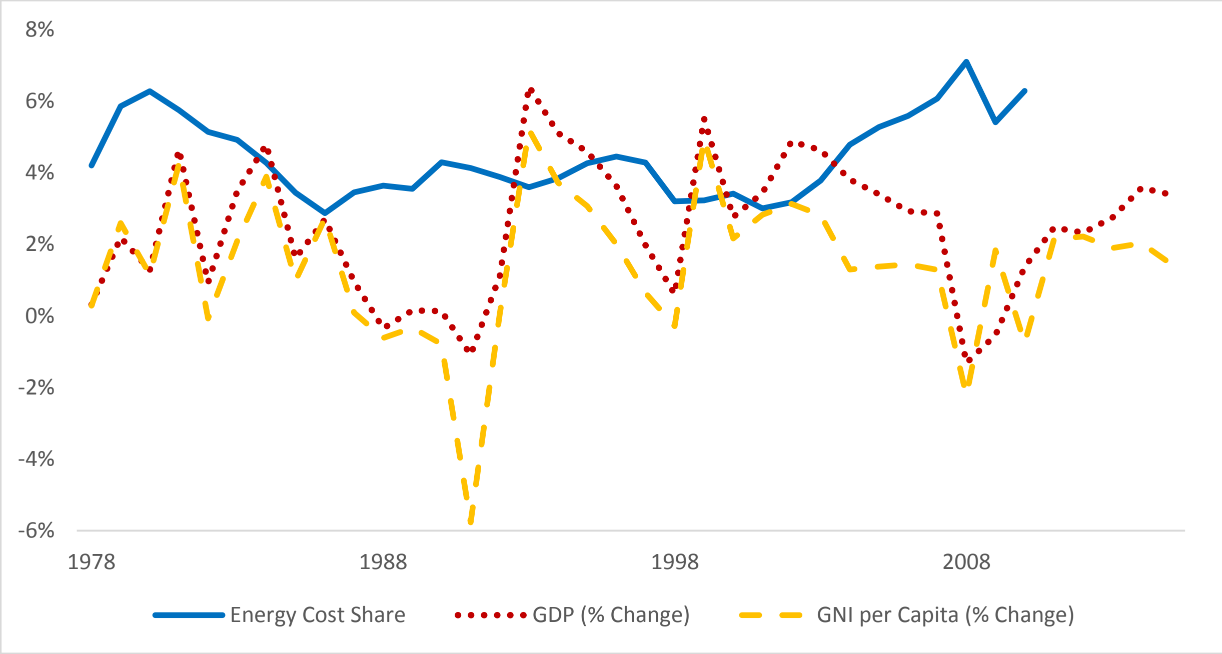

Figure 4.29: ECS, GDP and GNI per Capita Change – New Zealand

The health and education indices, seen in Figure 4.30, are remarkably high in comparison to other nations in this study. The health index gradually increases over the time period to reach a value of 0.95. The education index starts off at a low position on the graph, but after an acceleration in 2002, it ends at the same point. It is clear from the graph that both of these indices are unaffected by the varying ECS.

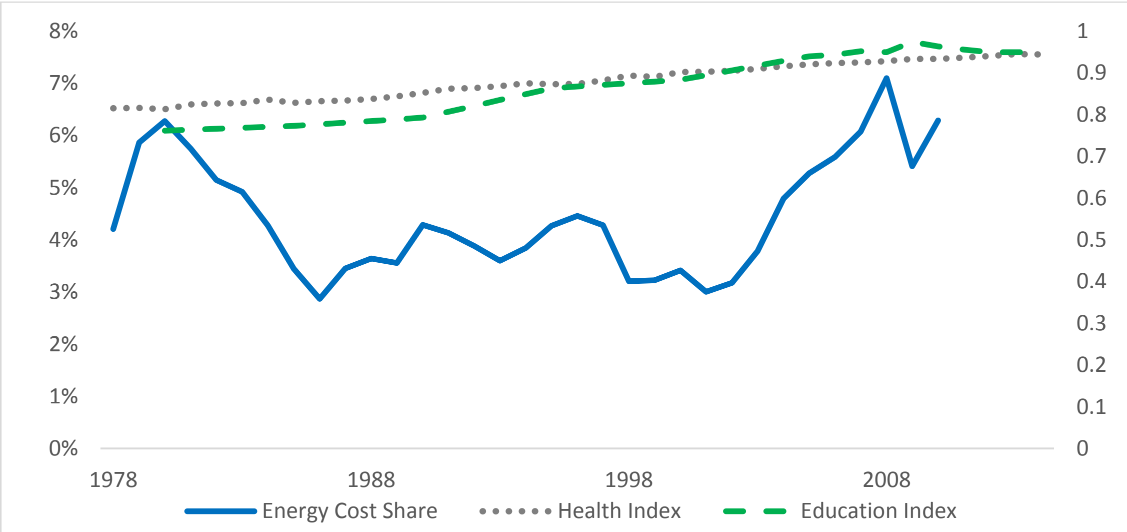

Figure 4.30: ECS, Health and Education Indices –New Zealand

As GDP and GNI per capita change seemed to react instantly to a change in ECS from the point of 2002 onwards, a zero year lag was considered when performing an overall correlation test. The results shown in Table 4.29 indicate that the overall effect of a change in energy expenditure has an immediate correlation on societal growth, with the correlation becoming weaker when the amount of lag is increased. The economy is affected most after a one year lag. The results of the overall correlation test were all seen to be statistically insignificant. This could be due to the noticeably different manner in which the New Zealand economy grew in comparison to the rest of the world, despite having a similar ECS shape to many countries.

Table 4.29: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags – New Zealand

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.211	0.239	-0.190	0.291
1	-0.273	0.125	-0.123	0.496
2	-0.144	0.422	6.4E-3	0.997
3	-0.081	0.654	0.083	0.643

A zero lag was also included in the ECS threshold test, the results can be seen in Table 4.30. Very little correlation was found for the high ECS peak seen in the beginning of the time period. This is not surprising as the GDP and GNI per capita change indices grew in a very odd manner, as mentioned above. Significant, negative correlations were established for the second period of high ECS values. A much stronger negative correlation was established between ECS and GNI per capita change than between ECS and GDP change. This could be seen from Figure 4.29 and is discussed above. In a similar manner to India, the strongest correlations between the ECS and these two indices were found without any lag being applied.

Table 4.30: ECS threshold test results – New Zealand

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1984	-0.018	0.972	-0.237	0.651	4.2% (One year lag)
2004-2010	**-0.690**	**0.085**	**-0.817**	**0.025**	**4.8% (Zero Lag)**

4.3. Regional Analysis

The data from each of these countries was then combined and analysed in terms of the regions in which they are found, namely North America, Europe, the BRICS nations and Australasia. Although strictly not a region, the BRICS nations were treated as a representation of fast developing third world nations.

As no correlation between ECS, health and education indices was found throughout the national analyses, it was omitted for the regional analyses. Although technically GNI is not the correct term to be used (as this is a regional and not a national analyses), it is kept the same to avoid unnecessary confusion.

4.3.1. North America

As the USA has by far the largest economy in the continent, it is no surprise that the shape of the North American ECS curve, seen in Figure 4.31 is very similar to that of the USA. The first ECS peak is seen to be slightly below 10% in 1980 before it falls to around 4% in 1988. It decreases gradually until 2002 where it starts to climb jto a second ECS peak near 7% in 2008. The shape of the GDP and GNI per capita change lines are also very similar to that of the USA, however, they have shifted slightly lower on the graph. The GNI per capita change line remains below the GDP change line throughout the time period given, making social standards more vulnerable to recessions.

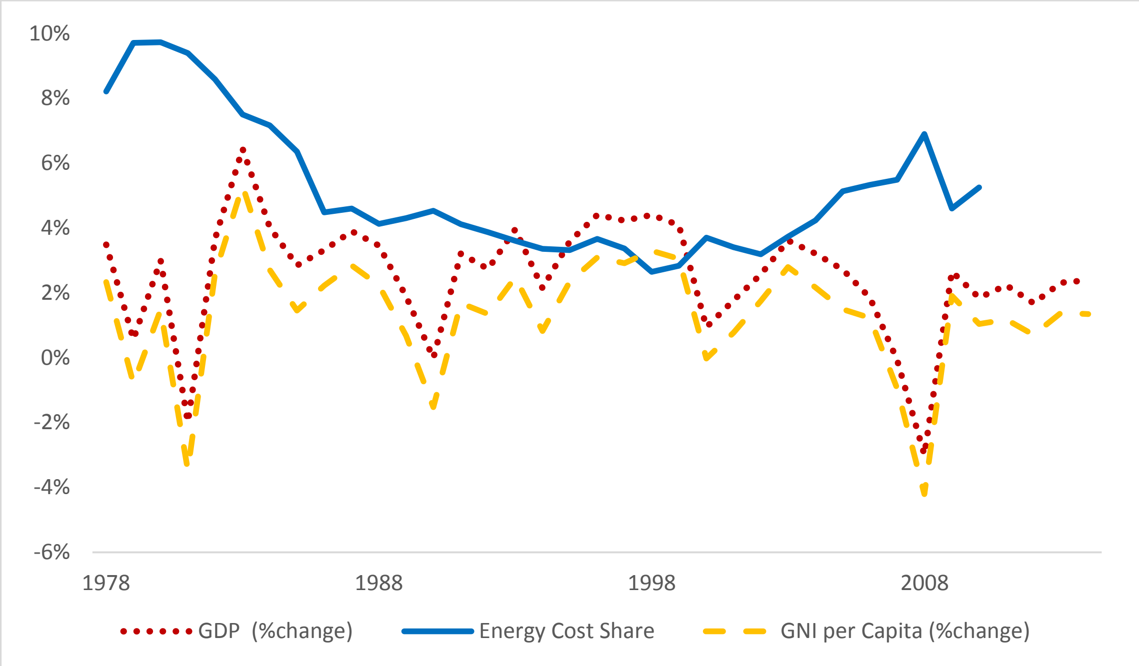

Figure 4.31: ECS, GDP and GNI per Capita Change– North America

Table 4.31 provides the results for the overall correlation tests. Due to the sheer scale of the US economy in comparison to its neighbours, it was expected that these results would be similar to those seen in the country analysis of the US. Much like those results, the ECS of the continent primarily affects GDP and GNI per capita change after a one year lag. Statistically insignificant correlations were also found when comparing the ECS with GDP change. It must be mentioned, however, that a correlation between GDP change and ECS with a one year lag recorded a *P*-Value of 0.122, very close to the significant standards of this analysis. A significant, negative correlation was found between the ECS and GNI per capita change. By performing a regional analysis and also including income levels, it can be determined that energy expenditures may not directly affect the economy, but they do play a role on social standards of the continent. This confirms the conclusions made about Figure 4.31, that the effects of a recession are felt most by society in this continent.

Table 4.31: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags – North America

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.175	0.330	-0.190	0.289
1	-0.275	0.122	**-0.319**	**0.071**
2	-0.127	0.480	-0.169	0.347
3	-0.004	0.981	-0.0.27	0.880

The ECS threshold test was then performed on the region, with the results can be seen in Table 4.32. Once again the size of the US economy played a significant role in these results. Even though no statistically significant correlations could be obtained for Canada and Mexico for the period from 1978-1984, the inclusion of the US to the data ensures that the whole continent has a very strong, negative correlation between ECS and GDP change. Similar values are obtained for GNI per capita change using an ECS threshold of 7.2%. Due to the links between the countries, the effects of one country can be felt over the whole continent. Extremely high, negative correlations were obtained between ECS and GDP change for the second ECS peak. A similar result was obtained between ECS and GNI per capita change. This was as expected as all the countries obtained correlations for this time period. What is of concern to Mexico and Canada is the fact that the ECS threshold is much smaller than the results of their own countries. Both thresholds are very close of that of the US.

Table 4.32: ECS threshold test results – North America

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1984	**-0.711**	**0.073**	**-0.720**	**0.068**	**7.2% (One year lag)**
2005-2010	**-0.833**	**0.020**	**-0.904**	**0.013**	**5.1% (One year lag)**

The massive economy of the US, originally built upon fossil fuels, is now sustained by supplies from both its neighbours. These exports have played, and still do play, a big role in the Canadian and Mexican economy. It is evident that one ripple in the US, such as a financial crises, could have ramifications for the entire continent. This may not be true for the other countries as Mexico's turbulent political climate of the past seems to have little effect on the overall development of the continent. From a purely economic perspective, it is obvious that the demand from the US has a massive role to play in its neighbour's economic fortunes. It is clear that the abundance of resources has allowed this continent to create economies on the backs of fossil fuels. It could be said that the access to large amounts of resources has led Canada and the US to be inefficient with energy, as both nations have the highest energy consumption per capita in OECD countries (IEA, 2015). Although Mexico is slightly less energy intense, it is tremendously dependent on fossil fuels to provide energy in the country. It also needs to import natural gas. Signs of depletion are evident, especially in USA and Mexico, and the hunger for energy from this continent puts these economies at risk as they look to other destinations for fuels.

4.3.2. Europe

From Figure 4.32 we see that Germany, Europe's largest economy, has influenced the ECS graph remarkably. Similar to the situation with the USA and North America. The gradual decrease from the first ECS peak in 1980 is a characteristic only seen in the ECS graph of Germany and, to a lesser extent, France (see Figures 4.9 and 4.7). Other countries in the region have a sharp reduction in ECS after the peak in 1980, followed by years of relatively small fluctuations. Looking through the energy cost share data, it was noted that Germany spent more on energy than the other countries in the region, especially before 1997. In some years this energy expenditure was more than double that of the next biggest spender, the UK. GDP and GNI per capita change are seen to be very close throughout the time period. Poor performance in these indices occurred after both peaks in ECS. The second period of poor performance is considerably worse than the first, even though the energy cost share was at a much lower level. Slow growth was also seen in 1992. As we can see from Figure 4.32, this had little to do with energy expenditure. Interestingly, the period with the lowest ECS brought a spike in GDP and GNI per capita change, around 1999. Although more data points of this nature would be needed to confirm the theory for this area, it may be that energy prices may have a lower threshold below which the economy is also dependent on its costs to stimulate development.

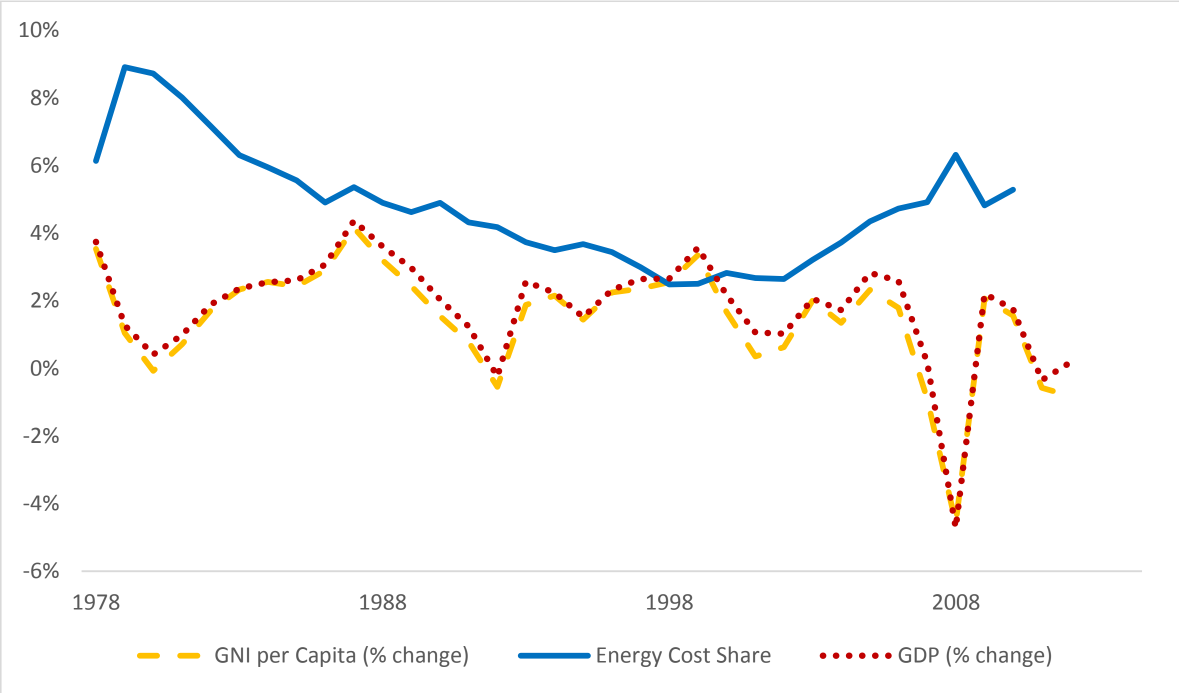

Figure 4.32: ECS, GDP and GNI per Capita Change - Europe

Table 4.33 shows the correlations between ECS, GDP and GNI per capita change for the entire period. There is a slight negative correlation, especially after one year, between ECS and GDP change. These are similar to the correlations between ECS and GNI per capita change. These results were seen to be statistically insignificant. Germany's effect on the data for Europe is confirmed in Table 4.33. During the country analysis, very little correlation was established between Germany's ECS and GDP change for the entire time period. Significant correlations between ECS and GDP change, as well as ECS and GNI per capita change, were established for all other countries within the region. The lack of significant correlations for Europe indicates that Germany has had a major influence on the results of the continent.

Table 4.33: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Europe

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.067	0.717	-0.065	0.723
1	-0.229	0.201	-0.206	0.062
2	-0.130	0.471	-0.108	0.197
3	-0.026	0.885	0.013	0.424

The results in Table 4.34 show that Europe has a strong correlation to an upper ECS threshold. Negative correlations were found when comparing ECS and GDP change during the first peak in ECS. This correlation was slightly weaker for the second peak in ECS, although still statistically significant. Similar results were obtained when comparing ECS and GNI per capita change.

Table 4.34: ECS threshold test results – Europe

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1985	**-0.857**	**0.007**	**-0.874**	**0.005**	**6.3% (One year lag)**
2005-2010	**-0.790**	**0.062**	**-0.758**	**0.08**	**4.3% (One year lag)**

This analysis stresses the importance of considering energy policy from a regional, as well as a national, perspective. If the results in Table 4.34 reflect the whole of Europe and energy policy is made purely from the European Union, many countries with their own energy dynamics may be neglected. On the other hand, energy policy made on a national level may have ramifications on other nations. Much like North America, the countries in Europe are all deeply connected. This is largely due to free trade agreements between countries. Even once the UK leaves the European Union it will still have strong ties with the continent. From an energy perspective, the continent is also linked by the synchronous grid. France, for example, can use this grid export any extra electricity supply to neighbouring countries. Likewise, other nations are able to purchase this electricity should demand exceed supply on their own country or if it is financially viable. Any disturbances in one country can have consequences throughout. Nations with higher ECS thresholds than the ones estimated for Europe may experience the effects of other nations suffering due to high energy prices, even though they should be, in theory, unaffected.

4.3.3. The BRICS Nations

Although strictly not a region, the BRICS nations represent the leading developing nations on the globe today. They also have significant influence within the region they are in. Looking at Figure 4.33, one can immediately notice the large range of ECS values over the time period. An ECS peak over 20% is seen in 1980, largely due to the massive energy expenditures at the time by Russia and China. The ECS line then decreases to just above 5% in 2002 before rising to a second ECS peak of 15% in 2008. India and Brazil also have ECS values above 10% in 2008, suggesting that the high second ECS peak cannot be attributed to ECS values of Russia and China alone. It is only South Africa that has ECS peaks much smaller than the ones seen in Figure 4.33. Further investigation noted that South Africa's economy size, as well as its energy expenditure, is magnitudes smaller than its fellow members. The GDP and GNI per capita change curves show a period of performance after the first high ECS peak, especially GNI per capita change which dips below the recession line. A slowdown in growth is also seen in 2008, however, both indices don't dip much below the 5% mark.

It is interesting to see that there is a large discrepancy between GDP and GNI per capita change in the start of the time period. This gap tends to decrease as time goes on and these two lines are much closer together at the beginning of the century.

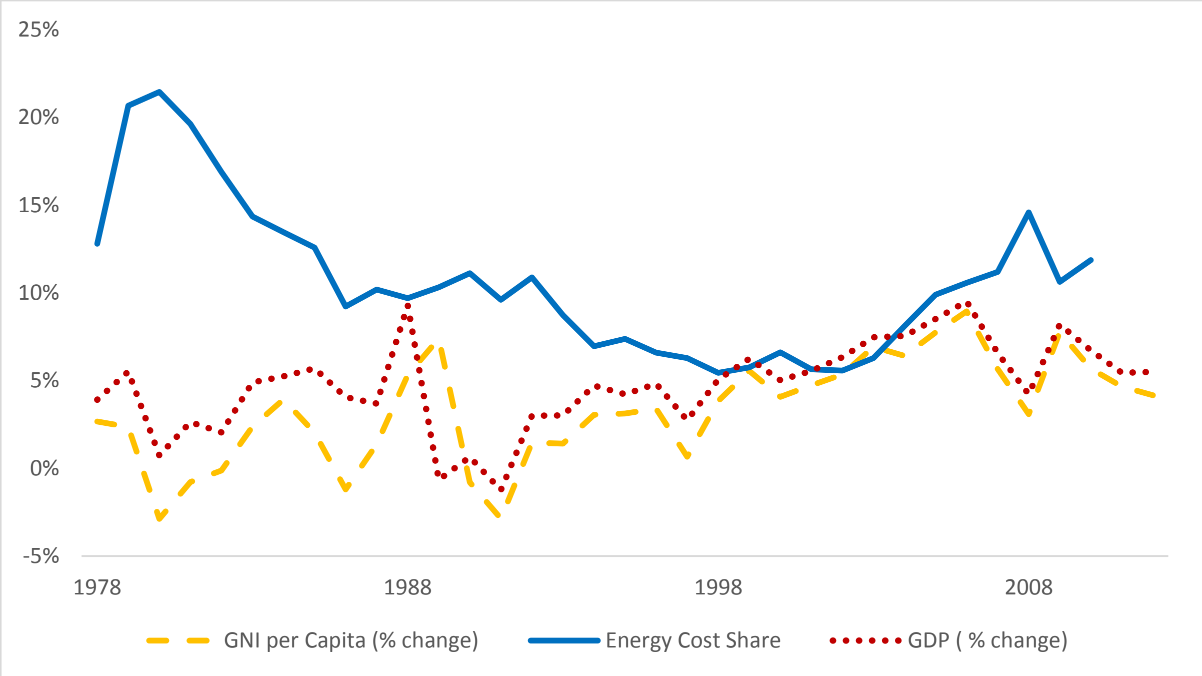

Figure 4.33: ECS, GDP and GNI per Capita Change – The BRICS Nations

The results establish for the overall correlations are particularly interesting. Looking at Table 4.35, we see that significant negative correlations were established between GDP change and ECS after a two and a three year lag. Negative correlations were established between GNI per capita change and ECS for one, two and three year lags. Furthermore, these correlations were stronger than those between GDP change and ECS. What is peculiar about these results is that none of the BRICS nations established significant overall correlations between ECS and GDP change as well as ECS and GNI per capita change. Yet when all the data is summed up and analysed, it reflects strong correlations for many year lags. One possibility for this occurrence could be that by combining all the data, a lot of the 'noise' in each country is perhaps cancelled out. Changes in economic and social development within a country can happen for a variety of reasons. Political and social instabilities occur in all countries, but perhaps even more so in third world nations. By aggregating the data, we are left with the weighted average GDP and GNI per capita change where the variations in these indices, due to slight political and social changes, are flattened out. In this case, the combined data gives a better reflection of how variations in energy expenditure can affect economic and social conditions, in aggregate, within emerging markets.

Table 4.35: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags – The BRICS Nations

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.146	0.424	-0.244	0.178
1	-0.265	0.136	**-0.410**	**0.018**
2	**-0.314**	**0.075**	**-0.488**	**0.004**
3	**-0.307**	**0.082**	**-0.455**	**0.08**

Taking into account that a two year lag generated the strongest correlations in the overall correlation test, it was also considered for the ECS threshold test. The results of which can be seen in Table 4.36 below. Very strong negative correlations were established between ECS and GDP change during the two periods of high ECS, namely 1978-1985 and 2005-2010. The correlation for the second period was stronger than that of the first, even though the estimated ECS was smaller. This tells us that the correlation between the combined economy of these third world nations and low energy expenditure has strengthened over time. A similar situation occurred when comparing the ECS and GNI per capita change, significant negative correlations were obtained for both time periods. It was noted that the correlation grew significantly between the time periods, more so than for ECS and GDP change. As urbanisation increases globally, more people are moving looking towards modern day sources of energy in order to live, for example catching a bus instead of riding a horse or using a stove instead of lighting a fire. Fuel costs are now becoming a concern to more people as it detracts from their discretionary income. The results seen in Table 4.36 could show this trend. This conclusion in results is vital to consider when planning energy policy as energy expenditure in these markets have more of an effect on the people than the economies of each nation.

Table 4.36: ECS threshold test results – The BRICS nations

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1985	**-0.841**	**0.009**	**-0.720**	**0.044**	**12.6% (Two Year Lag)**
2005-2010	**-0.915**	**0.011**	**-0.908**	**0.012**	**9.9% (Two Year Lag)**

The strongest correlations, for both the overall correlation test and the ECS threshold test, were established for a two year lag. This is different for the other regions of North America, Europe and Australasia, which all obtained correlations for a one year lag. This could be due to the way in which the global markets generally work. The BRICS nations, being developing countries, are dependent on offshore investment to stimulate growth. Nations from the other regions being analysed are mainly first world nations, who would generally supply this investment should it be more profitable than investing in their own country. Due to the cheap labour in most third world nation, this often is the case. As energy expenditures rise, investors are more hesitant to part with their money as the conditions are less favourable to make profits. The effect of this deficit in capital is perhaps more immediate in developed countries than developing countries. Two reasons can explain this. The all-round cheaper working conditions provided by third world countries often mean there is a greater lee-way for expenditures before a project becomes unprofitable. The second is that these offshore investments often involve some sort of contract that may take more time to get out off should the condition be necessary to do so. Market stability is widely recognised as a key aspect in attaining capital, be it private investment or funding from a financial institution. By creating more stable energy prices, independent of global fossil fuel dynamics, developing markets could take a step toward creating favourable market conditions. New infrastructure is necessary to accommodate rising population and urbanisation figures as it is. These nations have a chance to develop national energy supplies that are resilient to fossil fuel prices and any climate change initiatives that or on the horizon.

4.3.4. Australasia

The final regional analysis is that of the Australasian region. Although Australia and New Zealand do not make up the entire continent, as other smaller surrounding islands also fall within the region, these two countries are by far the largest in terms of population and economy. From Figure 4.34 we see that Australia's overwhelmingly larger energy expenditure affects the shape of the ECS curve. Even though both countries had an initial ECS peak above 6% in 1980, this high ECS value is maintained for three years before declining, as seen in the analysis of Australia. The influence of Australia is also apparent during the second ECS peak in 2008. New Zealand recorded an ECS value in excess of 7% in 2008, while the Australasian ECS at the same time is around 5%, much closer to the value seen in Australia. Comparing the GDP and GNI per capita change figures we can see that the GNI per capita change is significantly more unstable than economic development. Periods of poor performance in GDP change, seen in 1982, 1990 and 2008 also have GNI per capita change figures that are significantly lower. It is expected that social conditions will be strongly correlated to energy expenditures for this region, more so than economic conditions. As with Australia, it can be seen that higher development, both socially and economically, occur during periods of low ECS and the possibility of a lower ECS threshold will be investigated.

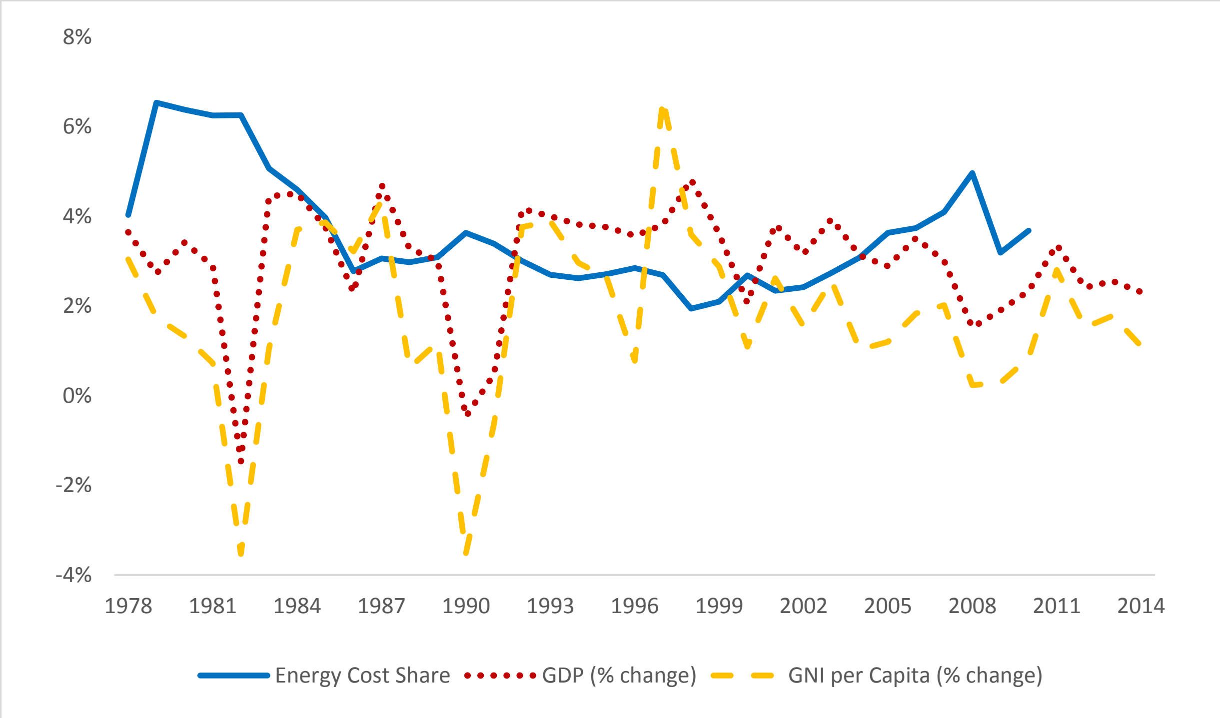

Figure 4.34: ECS, GDP and GNI per Capita Change - Australasia

Similar to that of the BRICS nations, the amalgamation of data from the two countries may have cancelled out some of the 'noise', thus providing stronger correlations for a regional analysis than a national one. The results of the overall correlation tests, seen in Table 4.37 show that a significant negative correlation was found between ECS and GDP change after a one year lag. Confirming the conclusions from Figure 4.34, a much stronger negative correlation was established between ECS and GNI per capita change for a one year lag. A significant, negative correlation was also obtained for a zero and two year lag between these two indices. The fact that a correlation between ECS and GNI per capita was found for a zero and a two year lag tells us that this correlation occurs for a longer period than originally calculated in the country analysis. Similar to that of Spain, a significant correlation was established between ECS and GNI per capita without any lag being applied.

Table 4.37: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags - Australasia

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.176	0.335	**-0.306**	**0.088**
1	**-0.329**	**0.062**	**-0.394**	**0.023**
2	-0.230	0.197	**-0.301**	**0.088**
3	-0.144	0.424	-0.162	0.369

The correlation coefficients are interesting as they are much stronger than the ones established for Australia during the country analysis. No correlation was established at all for New Zealand for the same test. By combining the two sets of data, we can perhaps get a greater understanding of how energy expenditures correlate to economic and social conditions in the region as the effects of other political influences may be flattened out. Higher correlations were obtained for the region between ECS and GDP change, as well as ECS and GNI per capita change, than for both countries.

The combination of data phenomenon is also evident in the ECS threshold test, the results of which can be seen in Table 4.38. No significant correlation was found between ECS and GNI per capita change for both countries during the first ECS peak from 1978-1985. Yet a fairly strong, negative correlation of -0.663 was obtained between these indices for Australasia. It was established in Section 4.2.14 that Australia had a lower ECS threshold, below which energy expenditure greatly correlated to economic and social development. As similar patterns could be seen in Figure 4.34, a lower threshold test was also conducted for Australia. From 1992-2004, a significantly strong, negative correlation was found between GDP change and ECS. The lower threshold value of 3% was estimated for this period. Interestingly, this correlation is stronger than the one established for Australia during this same period. This occurred even though New Zealand did not show any lower threshold characteristics.

An upper ECS threshold was also established between ECS and GNI per capita change from 2005-2010. A correlation of -0.844 was yielded, which is incredibly strong. Once again, this strong correlation is a surprise considering a statistically significant correlation was not established for Australia for this time period. A strong correlation was found for New Zealand for this time period, however, it was not as strong as this one.

Table 4.38: ECS threshold test results – Australasia

Years	**GDP Change**		**GNI per Capita Change**		**Estimated ECS Threshold**
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1985	-0.512	0.195	**-0.663**	**0.073**	**4% (One year lag)**
1992-2004	**-0.981**	**0.091**	**-0.972**	**0.028**	**3% (One year lag)**
2005-2010	-0.506	0.306	**-0.844**	**0.018**	**3.6% (One year lag)**

Looking at the estimated threshold, it seems there is a band between 3-3.5% where energy expenditure does not affect social or economic development. What is evident throughout this analysis is that social conditions are more severely correlated to energy expenditure than economic conditions in Australasia

4.4. All Countries

A combination of all the data was used to perform an "All Countries" analysis.

It would be convenient to make concrete claims about global trends from this analysis, however, we must be mindful of the fact that only fifteen countries are used (58 % of global GDP in 2015). With that being said, twelve of these countries are in the top fifteen global leading economies and more than four billion people reside in the countries of his analysis. By performing the "All Countries" analysis, it should give us an indication as to how developed or rapidly developing nations respond to varying energy expenditure. This is valuable knowledge as urbanisation is expected to rise rapidly over the next few decades.

From Figure 4.35 we can see that the ECS line has a similar shape to most developed nations. A high ECS peak above 10% is found in 1980, followed by a rapid decrease over the next five years. This decline continues at a steady rate until the turn of the millennium. From this point the ECS increases to a second ECS peak above 8% in 2008. This ECS graph is almost identical to that of King (2010b) which used 44 countries that made up approximately 95% of global GDP. Periods of poor performance are seen by both GDP and GNI per capita change after the two ECS peaks. These indices also dip in 1990, however, this cannot be attributed to high ECS values. It is noted that the GNI per capita change line is below the GDP change line throughout the period of the graph, indicating that it will have a stronger correlation should energy expenditure constrict development.

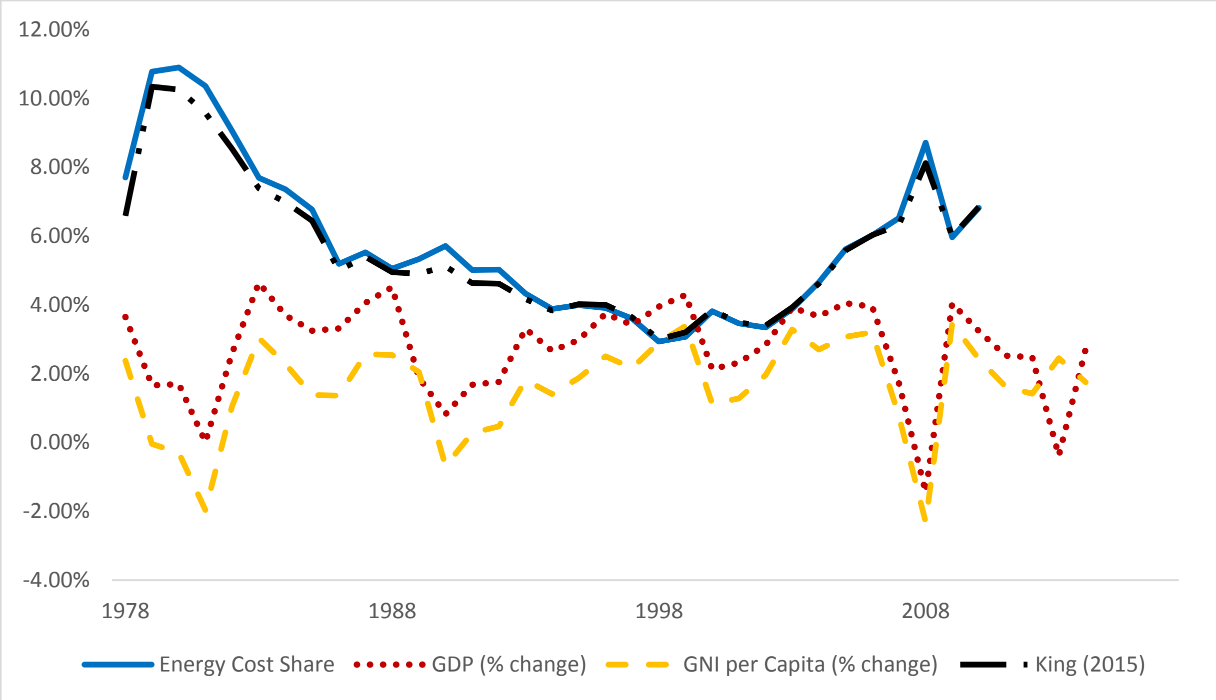

Figure 4.35.: ECS, GDP and GNI per Capita Change – All Countries

The results of the overall coefficient test, seen in Table 4.39, reveal a significant, negative correlation between ECS and GDP change for a one year lag. The correlation coefficient of -0.434 with a *P*-value of 0.012 is very close to that obtained by King (2015), which obtained a correlation of -0.447 at a *P*-value of 0.010. This can confirm that this analysis will give a good representation of global dynamics of ECS, GDP and GNI per capita change. The results obtained when comparing ECS and GNI per capita change are quite compelling. A much stronger negative correlation is obtained between ECS and GNI per capita change than the correlation between ECS and GDP change. Furthermore, statistically significant correlations between these two indices were found for zero, one, two and three year lags. Not only is the correlation of fluctuating energy expenditure stronger on social growth than economic growth, but it also occurs for a longer period of time.

Table 4.39: Overall correlation between ECS and both GDP and GNI per Capita change for multiple year lags – All Countries

Year Lag	GDP Change		GNI per Capita Change	
	Correlation	*P*-Value	Correlation	*P*-Value
0	-0.221	0.217	**-0.294**	**0.097**
1	**-0.434**	**0.012**	**-0.539**	**0.001**
2	-0.271	0.128	**-0.410**	**0.020**
3	-0.155	0.389	**-0.295**	**0.095**

The remarkably strong negative correlations, seen in Table 4.40, prove there is a global ECS threshold, above which economic development is highly dependent on energy expenditure. Statistically significant correlations were obtained when comparing ECS and GDP change for both periods of high ECS values. The ECS threshold test showed that GNI per capita change is similarly affected during these times.

The estimated ECS threshold reduced between periods, much like it did with most nations during the country analysis. Interestingly, the thresholds obtained are very close to those obtained for Germany, the USA and the UK. It was established in Section 4.2.8 that these countries behave in a similar nature to varying ECS values. The fact that a global representation has similar traits to these nations could show that a collapse in this group of economies will cause wide spread damage on the globe. Nowadays, China and Japan have become major player in the global market, however, the functioning of these three is essential to global growth.

Table 4.40: ECS threshold test results – All Countries

Years	GDP Change		GNI per Capita Change		Estimated ECS Threshold
	Correlation	*P*-Value	Correlation	*P*-Value	
1978-1985	**-0.857**	**0.029**	**-0.880**	**0.021**	**7.7% (One year lag)**
2005-2010	**-0.870**	**0.011**	**-0.846**	**0.016**	**5.6% (One year lag)**

4.5. Country Groupings

One of the aims of this study was to identify regions that could have similar dynamics to energy expenditures and many comparisons were made throughout. Within Europe, the Mediterranean countries of France, Italy and Spain had similar ECS traits throughout the time period analysed. These three countries, situated very close together, could make up a region of similar economic and social dynamics to energy expenditures. It was also noted that South Africa had similar ECS traits to the Mediterranean nations, which could be attributed to the Apartheid regime as well as similar climates. The shapes of the ECS lines over the period are very similar for all countries, with both the first and the second peak in ECS being roughly the same height. All have similar average ECS values over the period, with France's being slightly higher, as well as similar low ECS threshold values. Significant, negative correlations were also obtained for GDP and GNI per capita change for Italy, France and Spain for the overall correlation tests. The lack of overall correlation obtained for South Africa could largely due to other political changes, commonly seen in third world nations, which have affected the nation’s economy and society without affecting the Mediterranean nations. ECS threshold correlations were established for these countries, with these thresholds all within a 1% range. A possible reason why the average ECS for France is slightly higher could be because the nation invested heavily in nuclear power in the 1970's, which provided almost 40% of the nation's primary energy consumption in 2012 (Mearns, 2013). By using more nuclear power, France may have been be less affected by high oil price spikes than the other three nations. This resilience can be seen by the lack of correlations obtained for two or three year lags, where Italy and Spain are still feeling the effects of the changes in cost. Prices of energy production in this region may be very similar to all countries. Even if this is the case, variations in energy mix still play an important role in determining the effects of energy costs.

Russia and China make up another region of similar dynamics to varying energy costs. These countries have remarkably high ECS values around 1980, over 30%! An extremely high average ECS of around 15% is also recorded for both of these nations. This average is significantly higher than any of the other nations analysed. The resilience of these countries' economies to high energy expenditures is also very interesting. In the face of an energy cost share above 30%, Russia's GDP and GNI per capita change indices have no reaction. For the same period, China recorded an ECS value of almost 45%. The GDP and GNI per capita change indices did falter somewhat, however, the high growth rate in the country meant these indices dropped to 5%, higher than global averages for the entire time period analysed. High ECS values from 2005-2010 had a slightly stronger effect on these two countries, although it was small in comparison to other nations being analysed. A possible reason for this could be that both these countries produce most of their own fuel. They, therefore, do not feel the effects of escalating global fuel prices. Furthermore, accurate prices for these fuels could not be obtained and assumptions had to be made. It is a possibility that these assumptions may have led to inflated ECS values. The same argument can be said for the GDP and GNI per capita change data used before 1991. Alternative sources had to be used to obtain values, discussed in Section 3. Another reason could be that these two countries have planned economy principles, at least until the early 1990's. This could have protected Russia and China from the global downswing in the late 1970's. By 2009, China had adopted some traits of a market economy, with Russia seemingly have made a transition away from socialism. This provides a reason as to why Russia experienced a decrease in GDP and GNI per capita figures when experiencing high ECS in 2009 and not in the late 1970's. A slight dip in GDP and GNI per capita was seen in China during these periods of high ECS, possible due to the limited market economy principles, however, the country experienced high growth rates throughout the period.

The comparisons spread beyond geographic boundaries though. The USA, UK and Germany have also been identified as having similar trends. As discussed in Section 4.2.8, the estimated ECS thresholds for these three countries for the two periods of high ECS were very similar. Moreover, these countries had much stronger correlations for the second peak in ECS, even though the estimated ECS threshold for the second period was lower than that of the first. The UK and Germany have similar trends in energy mix over the period being analysed. The composition of oil and coal within the energy mix decreases over the time period, with an increase in natural gas, nuclear and renewable energy. The growth in natural gas is much more rapid in the UK than in Germany, which has attempted to substitute oil and coal with more nuclear and renewable sources. In a similar fashion, the US has decreased its composition of oil in its energy mix, however, it has substituted this with a larger inputs from coal and natural gas. Nuclear and renewable energy resources are also increasing, but not at the rate seen in Germany. The composition of fuel sources for these countries is similar, but not exactly the same. Another reason why these countries have similar trends may be because these three nations have been consistently been the most developed, socially and economically, out of all the nations analysed. China and Japan do have economies larger than that of the UK and Germany, but this has only occurred in recent times. The fact that the UK, USA and Germany have consistently been global powerhouses may have influenced the energy mix of these three nations as well as how their society now reacts towards a change in energy costs.

4.6. Summary of Results

There is an obvious correlation between energy expenditure and the development of economies. Significant correlations were established for fourteen of the fifteen countries analysed, all four of the regions as well as the "All Countries" analyses. These relationships were discovered even though all the countries analysed, especially the third world nations, have faced many other issues throughout the period that may have disturbed the GDP growth indices and not the ECS values.

It was noted that the significant correlations established were much stronger, as well as more significant, during periods of high ECS than for the overall period. Table 4.41 below gives a summary of the correlations between GDP change and ECS for each country. The strongest significant correlations for both the overall correlation test and the ECS threshold test are tabulated. Many more significant correlations were obtained during periods of high ECS. The average correlation coefficient during periods of high ECS is seen to be -0.870, much larger than that of the average overall correlation coefficient of -0.377. This validates the proposition by Bashmakov (2007) that states that the economy becomes highly dependent on energy costs once a threshold has been exceeded. The threshold hold values obtained for the USA in this study are similar to the ones obtained by Bashmakov (2007); Aucott & Hall (2014) and King (2015).

The estimated ECS threshold value for the first period of high ECS, from around 1978-1985, was generally higher than that of the threshold established during the second period of high ECS, from 2005-2010. Economies were severely affected by the financial crises of 2009, drastically reducing the demand and price of energy. It could be that if this did not occur, the same threshold would have been reached. Another, more plausible, reason could be that economies have become more dependent on fuel, especially low cost fuel, to generate growth. Thus they are strongly correlated to high ECS values. Many nations experience 'aftershocks' after an economic recession, which could be validated by the high energy expenditures that have not yet reduced low enough to stimulate economies.

The existence of a lower ECS threshold may also occur. In this case, economic growth is highly dependent on low ECS values. Evidence of this was found during the analysis of India, Spain and Italy, however, it was proven to be the case for Australia. Significant, negative correlations between the economy and ECS values were only established for periods of low ECS. As Australia is a major exporter of coal, especially to the Asian market, the results may not reflect the direct effect energy expenditure on the country but rather how the global trend of energy expenditure affect this country's economy. However, this theory does not explain why the country is not affected by periods of high ECS, a deeper investigation into this is needed.

Table 4.41: Strongest significant correlations between GDP change and ECS found in each country and region

GDP Change							
Country	**Overall Correlation**	***P*-Value**	**Year lag**	**High ECS Correlation**	***P*-Value**	**ECS Threshold**	**Year Lag**
Australia	-0.304	0.086	1	-0.681	0.004	3.4% (Lower Threshold)	1
Brazil	-	-	-	-0.898	0.038	6.5%	2
Canada	-0.319	0.070	1	-0.943	0.005	6.8%	1
China	-	-	-	-0.842	0.018	25.2%	1
France	-0.340	0.053	1	-0.949	0.013	4%	1
Germany	-	-	-	-0.854	0.065	5.1%	1
India	-	-	-	-	-	-	-
Italy	-0.351	0.045	1	-0.854	0.029	3.9%	2
Mexico	-	-	-	-0.958	0.004	6.4%	1
New Zealand	-	-	-	-0.690	0.085	4.8%	0
Russia	-	-	-	-0.866	0.026	11.6%	1
South Africa	-	-	-	-0.855	0.014	3.4%	1
Spain	-0.661	2.9E-5	2	-0.855	0.030	4.3%	1
UK	-0.337	0.055	1	-0.900	0.014	4.9%	1
USA	-	-	-	-0.939	0.005	4.9%	1
Region							
Australasia	-0.329	0.062	1	-0.981	0.091	3% (Lower Threshold)	1
BRICS	-0.314	0.075	2	-0.915	0.011	9.9%	2
Europe	-	-	-	-0.857	0.007	6.3%	1
North America	-	-	-	-0.833	0.020	5.1%	1
All Countries	-0.434	0.012	1	-0.857	0.029	7.7%	1
Average	**-0.377**	**0.050**	**-**	**-0.870**	**0.027**	**-**	

By looking at the effects of energy expenditures on human development, this study obtained very interesting results. An ECS threshold also existed for GNI per capita change, much like GDP change. It was also noted throughout that GNI per capita had a greater reaction to varying energy cost shares. Table 4.42 below gives a summary of the correlations between GNI per capita change and ECS for each country. The strongest significant correlations for both the overall correlation test and the ECS threshold test are tabulated. Similar to Table 4.41 the stronger correlations established during high ECS indicate a threshold. The average correlation coefficients of Table 4.41 and Table 4.42 provide evidence that high ECS values are strongly correlated to the global development of society, more so than on the economy. This occurs during periods of high and low ECS.

Table 4.42. Strongest significant correlations between GNI per capita change and ECS found in each country and region

GNI per Capita Change							
Country	**Overall Correlation**	***P*-Value**	**Year Lag**	**High ECS Correlation**	***P*-Value**	**ECS Threshold**	**Year Lag**
Australia	-0.343	0.051	1	-0.655	0.006	3.4% (Lower Threshold)	1
Brazil	-	-	-	-0.884	0.047	6.5%	2
Canada	-0.354	0.043	1	-0.907	0.013	6.8%	1
China	-	-	-	-0.836	0.019	25.2%	1
France	-0.315	0.074	1	-0.940	0.018	4%	1
Germany	-	-	-	-0.835	0.078	5.1%	1
India	-	-	-	-	-	-	-
Italy	-0.381	0.029	1	-0.885	0.019	3.9%	2
Mexico	-	-	-	-0.934	0.006	6.4%	1
New Zealand	-	-	-	-0.817	0.025	4.8%	0
Russia	-	-	-	-0.860	0.028	11.6%	1
South Africa	-	-	-	-0.923	0.003	3.4%	1
Spain	-0.671	1.9E-5	1	-0.962	0.002	4.3%	1
UK	-0.301	0.088	1	-0.910	0.011	4.9%	1
USA	-	-	-	-0.960	0.002	4.9%	1
Region							
Australasia	-0.394	0.023	1	-0.972	0.028	3% (Lower Threshold)	1
BRICS	-0.488	0.004	2	-0.908	0.012	9.9%	2
Europe	-	-	-	-0.874	0.005	6.3%	1
North America	-0.319	0.071	1	-0.904	0.013	5.1%	1
All Countries	-0.539	0.001	1	-0.880	0.021	7.7%	1
Average	**-0.411**	**0.038**	**-**	**-0.887**	**0.029**	**-**	

What is not shown in this table is the period which ECS affects GNI per capita change. The results from Table 4.39 show that ECS values have an effect on GNI per capita for zero, one, two and three year lags. This indicates that the correlation not only is stronger to social growth, but has a longer duration.

Splitting the HDI into its three components provided insight into how energy expenditures affect income, health and education levels. As discussed earlier, energy costs have a major impact on income levels. The idea that ECS can affect GDP change and, especially GNI per capita change, without affecting the health and education in the country is difficult to comprehend. Yet this occurs with all the countries analysed. When thought about in a mechanistic manner, if a government is spending more money on energy sources, it will have less money for education and health expenditure for its people. On a societal level, people may have to sacrifice health or education benefits in order to pay for energy sources. There are few reasons why these results could counteract this 'logical' approach. The first is that health and education systems of most of these nations are extremely good and do not waiver in the face of varying energy expenditure. These two social issues may be given a higher priority than economic development, and, therefore, are not affected by any budget cuts very drastically. Advances in technology may have also have had a more influential role in these two sectors. It has become much easier to access information thanks to the ever growing communications market. The discovery of penicillin has had major effects on world health. Not only is it extremely effective in combatting disease in humans, it is also used widely in the food sector, allowing food supplies to drastically increase. These innovations may be more significant that the effect energy cost has on the health and education. Another, more viable, reason could be that the indices used to monitor the state of health and education of the countries may not be responsive enough show any fluctuations. For example, if a scholar cannot afford proper health care or enough food, it could reflect in her performance at school. It is difficult to think if you are hungry or sick and a sub-standard performance is likely. Even though she managed to pass all her tests and obtain her qualification, she would not be able to gather as much knowledge and understanding that she could have. This loss could later have an effect on economic growth. Furthermore, the education and health data points are only ever taken every five years, with the points in-between being interpolations. As discussed in Section 3.4.1, other health and education metrics were looked at, but it was very difficult to get any datasets for this period. This goes back to the importance of accurate data collection highlighted throughout Chapter 3.

Most studies previously done in this field generally consider one year lag when comparing ECS and the US economy. King (2015) used a one year lag to obtain any correlations between ECS and GDP change for a range of countries. Although the strongest correlations were obtained with these time lags for many of the countries in this analysis, it certainly is not the case for all. Significant correlations were found for zero, two and three year lags for many countries and regions in this analysis.

The inclusion of these lags reveals the duration of time the economy and society are correlated to high energy expenditures. This can be seen by the time lag used to establish the ECS thresholds. The correlations may be also be immediate, as seen in the case of New Zealand and Spain, or it may take up to two years for the signs of high energy expenditures to show, as seen in Italy. It was interesting to note that the analysis of the BRICS nations revealed a two year time lag during periods of high ECS brought the sharpest response by GDP and GNI per capita change figures. This is indicative of global market dynamics as these nations are dependent on offshore investment to stimulate growth. It may take more time for the lack of investment, due to high energy expenditures, to have its effects on the developing nation. In general, the second period of high ECS, form 2005-2010, brought a much more immediate response by countries than in the first period of high ECS. This provides further evidence that nations have become more dependent on fuel, especially low cost fuel, to generate growth.

The consideration of multiple year lags also revealed the duration of time needed by an economy or society to recover from a period of high energy expenditure. This can be seen by significant correlations obtained for multiple time lags for the overall correlation tests. Significant correlations between GNI per capita change and ECS were often established for multiple year-lags. This noticed in the country analysis, but more so in the regional analysis and ‘All Countries’ analyses. These results indicate the importance of considering high energy expenditures as it can constrict economic and social development for years after energy expenditure has been reduced.

The investigation into the energy dynamics of specific regions provided very interesting results. It was noted that a higher percentage of the correlations obtained, in both the overall correlation test and the ECS threshold test, were seen to be stronger and statistically significant. Furthermore, these results were seen in places where the individual nations making up the regions did not produce any correlations in the same places as the region. None of the BRICS nations, for example, established significant overall correlations between ECS and GDP change as well as ECS and GNI per capita change. Yet when all the data is summed up and analysed, it reflects strong correlations for many year lags. Australasia provided another good example of this as ECS thresholds were established for three different time periods for the region, but only one was established for each nation. A possible reason for this occurrence could be that by combining all the data, a lot of the 'noise' in each country is perhaps cancelled out. Changes in economic and social development within a country can happen for a variety of reasons. Political and social instabilities occur in all countries, but perhaps even more so in third world nations. By aggregating the data, we are left with the weighted average GDP and GNI per capita change where the variations in these indices, due to slight political and social changes, are flattened out. In this case, the combined data gives a better reflection of how variations in energy expenditure can massively affect economic and social conditions within emerging markets.

As one of the objectives of this study was to identify certain regions with similar energy cost dynamics, county comparisons were made throughout this study. An investigation into why these countries reacted in similar trait was also performed:

- The nations from the Mediterranean region (Italy, France and Spain) as well as South Africa, were all seen to have similar traits. These included having similar ECS shapes over the period being analysed, very similar estimated ECS thresholds as well as correlations with roughly the same magnitude. Italy, France and Spain, situated very close together, could make up a region of similar economic and social dynamics to energy costs. This may be because actual prices to produce energy in this region may be very similar to all countries. Three possibilities could give reasons why South Africa's ECS curves are similar to those of the Mediterranean nations. One is the climate is similar. The second is that the Apartheid regime may have split the nation into two. With one part of society controlling most the wealth, establishing an economy similar to the dynamics of a European country. The majority of society was tasked with providing cheap labour in order for big business to succeed. Lastly, many of South Africa's poor use biofuel for their energy needs. By excluding biofuels this study focusses more on the nation's wealthy residential and business sector.

- Russia and China make up another group of countries with similar dynamics. Both these nations had extremely high ECS peaks around 1980, a very high average ECS value throughout the period as well as resilience towards high energy costs. Reasons explaining these traits included the fact that these countries have large amounts of fuel stocks that supply their nation with fuel. These nations also included planned economy principles that may have allowed their countries to react differently in the face of high ECS prices.

- The comparisons were also noted for a group of countries that were not situated close together geographically. These were Germany, the UK and the USA. The estimated ECS thresholds for these three countries, for the two periods of high ECS, were very similar. Furthermore, these countries had much stronger correlations for the second peak in ECS, even though the estimated ECS threshold for the second period was lower than that of the first. Although the energy mixes of these countries had similarities, a more plausible reason for the common dynamics was identified to be the strong economies these countries have possessed throughout the period being analysed. It was also noted that global energy dynamics were very similar to these nations, indicating that a collapse in these three economies will cause wide spread damage on the globe.

Chapter 5 - Conclusions and Recommendations

5.1. Introduction

Rising global temperatures and fossil fuel depletion have called for a shift towards renewable energy. The overarching goal of this paper was to investigate how a transition to an energy sector dominated by renewable energy systems would affect the other two pillars of sustainability, namely society and the economy. The literature analysis in Chapter 3 identified that varying energy expenditure, which could result from a transition to different energy sources, could indeed affect economic development. The existing literature mainly focussed on global and US trends and did not provide go into any great detail about these dynamics. Furthermore, none of the existing literature linked energy costs to human development. From this, a list of objectives for this study was established:

Objective 1: To examine the relationship between energy costs and economic growth for selected countries from different regions.

Objective 2: To examine the relationship between energy costs and human development for selected countries from different regions.

Objective 3: To identify the correlation between energy costs and economic growth; as well as energy costs and human development for selected countries from different regions.

Objective 4: Conduct a regional analysis of the countries gathered

Early on, it was established that finding accurate data may be difficult. It would also not be possible to produce comparable results should different data sources be used. With data - along with a comprehensive methodology to replace missing data that could not be found - being obtained from the study of King (2015), tests were designed in order to fulfil the objectives set out and investigate the dynamics between energy costs and human and economic growth. This chapter follows with key findings from these tests. Section 5.3 recognises the limitations of this study, with recommendations to overcome these limitations as well as further research provided in Section 5.4.

5.2.Key Findings

This study confirmed the research proposition that high energy expenditure is negatively correlated to economic growth, adding to the existing literature supporting this theory. The findings from this study, however, showed that each country has its own set of dynamics to energy cost share. The existence of an ECS threshold suggested by Bashmakov (2007) was validated in many countries/regions with very strong correlation coefficients being obtained for periods of high ECS. With the unique characteristics of each country being displayed, this threshold should not be assumed based on world data, rather be investigated by each country. Furthermore, countries may be strongly correlated to low energy expenditure, as in the case of Australia. These countries may rely heavily on low global fuel prices in order to stimulate exports and boost their economies. There are also varying time lags between the high energy expenditure and the correlation to economic growth. Some countries appear to react instantly to high ECS (New Zealand and India) and some seem to take longer (Italy). This further confirms the complexity of the energy system discussed in Section 2.3.

Acknowledging the importance of social growth, this study investigated the effect of energy cost share on human development and was met with mixed results. Throughout the study it was noticed that energy cost share had a very strong correlation to GNI per capita change, much stronger than the correlation between ECS and GDP change. This revelation is very evident in the regional analysis and, most noteworthy, the 'All Countries' analysis, which is shown to give a fair representation on global energy cost share dynamics. Not only were the correlations stronger, they also affected GNI per capita change for a period of four years. The use of ECS may be good tool for stimulating economic growth, but more importantly it stimulates human development in the form of income levels. On the other hand, ECS showed to do very little in affecting the education and health indices of each country. This could suggest that the health and education systems of each country are fairly resistant to fluctuating energy expenditure. Considering the drastic effect the ECS had on GNI per capita levels, it is more likely that these indices do not accurately represent that relationship between energy expenditure and health and education levels, with more research into this topic being suggested.

Section 4.3 confirmed the proposition that economic and human development is affected differently in different regions of the world. There was very little overall correlation between economic and social expenditure for North America and Europe. These areas, however, have a strong correlation to an ECS threshold. The BRICS nations obtained significant correlations for both the overall correlation test as well as the ECS threshold test, with the strongest correlations coming after a two year lag. Australasia seems to experience a lower ECS threshold, below which ECS levels have a correlation to economic development. Much like the BRICS nations, GNI per capita change is affected more severely than GDP change. It was found that stronger, and more statistically significant, correlations were obtained when conducting regional analyses. It was proposed that the combined data gives a better reflection of how variations in energy expenditure can massively affect economic and social conditions. Many of the fluctuations in economic and social change, not caused by varying energy expenditures, are evened out when using regional data.

This follows on to the last key finding, that many influences can affect the dynamics of energy costs on a countries economic and human development. The effects may be localised to a specific region, for example the Mediterranean region and the Asian region of Russia and China. There are many other factors that can play a vital role such as a country's energy mix, economic situation and political history. The similarities in results of Germany, the UK and the USA show that countries from vastly different backgrounds can all react in a similar fashion due to economic positions in the globe. Regional data is useful in cementing the correlations of ECS on social and economic development, however, country level studies should be coordinated in order to establish specific thresholds, correlations etc. This is vital considering energy policy is made primarily at a national level.

Once overall correlations and thresholds are established, countries can plan an energy mix that is capable of avoiding economic and social decline whilst transitioning towards a power sector dominated by green energy, so desperately needed by the environment. By linking ECS to EROI, as shown in Equation (5), this tool can be used on a project level in order to determine the feasibility of a new power generating system. Of late renewable energy costs are rapidly falling, with most countries actively pursuing solar and wind power as it provides a cheap, reliable and, most importantly, a clean source of energy.

But what happens if a green economy is 'too expensive'? Favourable conditions are only available in some parts of the world and for certain countries fossil fuel power generation may be a much cheaper option. A shift toward renewable energy may breach an ECS threshold and cause a country to fall into an economic recession. Should this be the case, it is important to note that even though there are three pillars to sustainability, the economy and society are in essence within the environment. Without Mother Nature, there is nothing. The global fascination of non-stop growth, constantly pushing the boundaries may need to be revised to one that accepts the limits of our world and focuses on prosperity and fulfilment within.

5.3.Limits of Study

The study was limited by lack of time series data availability on energy pricing as well as human development indicators. A methodology was created in order to replace these data points, however, it is acknowledged that this substitution will not give perfect results.

The lack of data leads on to the next point of including biomass as an energy stock in the energy cost share. Reliable, country specific data could not be found with regards to price and consumption, leading to the omission of this fuel source from this study. Fizaine & Court (2016) provide a methodology to estimate biomass costs and consumption for the US, however, this is not accurate for other countries.

A wide variety of countries were chosen from many regions for this study in order to make comparisons between the them Although a brief investigation explaining the results obtained was provided, the study did not delve deep into the dynamics of each nation.

5.4. Recommendations into further research

Following on from Section 5.3, further research could be limited to a few countries in one region, with a deeper investigation explaining the dynamics of energy costs each nation. Zooming in to one country could provide better information with regards to energy consumption and prices. This could perhaps provide a country specific methodology to include biomass in the analysis as well as methodology to exclude variations in economic and social changes due to other factors other than energy costs. This study has shown that each country reacts to energy costs in a different manner and as most energy policies are made at a national level, in-depth knowledge could prove invaluable.

The fact that energy costs could drastically effect GNI per capita change and not have an effect on health and education statistics also deserves further research. An investigation into what the shortfall of disposable income will affect is vital to know. It is likely that this will vary from region to region and, even more so, vary from households with different income levels.

As it has been shown that energy expenditure play an important role in economic and social development, they should be monitored and used as a policy tool. Most countries are likely to see large increases in population in the near future and it is vital for them to monitor energy expenditures in order to facilitate a smooth transition towards a cleaner energy market for their people. It is recommended that price and consumption data of fuel sources be recorded in order to use energy cost share as a policy making tool.

Chapter 6 - Bibliography

Bibliography

Africa Business, 2016. Africa's Energy Challenge. *Africa Business*, May, p. 57.

Arshad, A., Zakaria, M. & Junyang, X., 2015. Energy prices and economic growth in Pakistan: A macro-economic analysis. *Renewable and Sustainable Energy Reviews,* pp. 25-33.

Aucott, M. & Hall, C., 2014. Does a Change in Price of Fuel Affect GDP Growth? An Examination of the U.S. Data from 1950–2013. *Energies*, Volume 7, pp. 6558-6570.

Bashmakov, I., 2007. Three laws of energy transitions. *Energy Policy*, Volume 35, pp. 3583-3594.

Biggs, R. et al., 2012. Towards Principles for Enhancing the Resilience of Ecosystem Services. *Annual Reviews in Environment and resources.*

Bill Hopwood, M. M. a. G. O., 2005. Sustainable Development: Mapping Different Approaches. *Interscience*, Volume 13, pp. 38-52.

Blewitt, J., 2008. World Views and Ethical Values: Towards a Paradigm Shift. In: *Understanding Sustainable Development.* London: Earthscan, pp. 41-42.

BP, 2014. *BP Statistical Review of World Energy June 2014*, London: BP.

Brundtland, G. H., 1987. *Our Common Future*, s.l.: UN.

Canada, P. T., 2007. *Power Tube Canada.* [Online]
Available at: (http://powertubecanada.com/about_us
[Accessed 1 June 2017].

Chang, T.-H., Huang, C.-M. & Lee, M.-C., 2009. Threshold effect of the economic growth rate on the renewable energy development from a change in energy price: Evidence from OECD countries. *Energy Policy*, pp. 5796-5802.

Curtis, G. E., 1996. *Russia: Acountry Study*, Washington: Libraray of Congress.

Dale, M., Susan, K. & Bodger, P., 2011. A Dynamic Function for Energy Return on Investment. *Sustainability*, Issue 3, pp. 1972-1985.

D'amelio, M., Garrone, P. & Piscitello, L., 2016. Can Multinational Enterprises Light up Developing Countries? Evidences from the Access to Electricity in sub-Saharan Africa. *World Development*, 88(1), pp. 12-32.

Department of Health South Africa, 2012. *The 2011 National Antenatal Sentinel HIV & syphilus prevalence survey in South Africa*, Pretoria: Department of health South africa.

EIA, 2011. *Annual Energy Review 2011*, Washigton, DC: EIA.

Fioramonti, L., 2013. *Gross Domestic Problem: The Politics Behind the World's Most Powerful Number*. s.l.:Zed Books.

Fisher, N. & Downes, G., 2015. *IEA*. [Online]
Available at: https://www.google.com/search?q=iea+south+africa&ie=utf-8&oe=utf-8&client=firefox-b-ab&gfe_rd=cr&ei=QMs6WdrpDoyp8we6-oj4BQ
[Accessed 8 June 2017].

Fizaine, F. & Court, V., 2016. Energy expenditure, economicgrowth, and the minimum EROI of society. *Energy Policy*, pp. 172-186.

Gan, J. & Smith, C. T., 2011. Drivers for renewable energy: A comparison among OECD countries. *Biomass and Bioenergy*, pp. 4497-4503.

Government of Australia, 2015. *Coal in India*, s.l.: Government of Australia.

Hartley , P., Medlock III, K. B., Temzelides, T. & Zhang, X., 2016. Energy Sector Innovation and Growth: An Optimal Energy Crisis. *The Energy Journal*, 37(1), pp. 233-258.

Heun, M. K., 2016. *Energy and the Macroeconomy: 5 Propositions*. s.l.:s.n.

Heun, M. K. & de Wit, M., 2011. Energy return on (energy) invested (EROI), oil prices, and energy transitions. *Energy Policy*, Issue 40, pp. 147-158.

Heun, M. K. et al., 2017. From Theory to Econometrics to Energy Policy: Cautionary Tales for Policymaking Using Aggregate Production Functions. *Energies*, Issue 10.

Hopwood, B., Mellor, M. & O'Brien, G., 2005. Sustainable Development: Mapping Different Approaches. *Sustainable Development*, Issue 13, pp. 38-52.

IEA, 2008. *World Energy Outlook*. [Online]
Available at: http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo2008.pdf
[Accessed 28 March 2016].

IEA, 2015. *IEA*. [Online]
Available at: https://www.iea.org/countries/membercountries/canada/
[Accessed 1 June 2017].

IEA, 2015. *IEA.* [Online]
Available at: https://www.iea.org/countries/non-membercountries/mexico/
[Accessed 1 June 2017].

IEA, 2016. *Energy and Air Pollution,* Paris: IEA.

IEA, 2016. *World Energy Outlook,* Paris: IEA.

Kanagawa, M. & Nakata, T., 2007. Analysis of the energy access improvement and its socio-economic impacts in rural areas of developing countries. *Ecological Economics,* Volume 62, pp. 319-329.

King, C., 2015. Comparing World Economic and Net Energy Metrics, Part 3: Macroeconomic Historical and Future Perspectives. *Energies,* Issue 8, pp. 12997-13020.

King, C., Maxwell, J. & Donovan, A., 2015. Comparing World Economic and Net Energy Metrics, Part 1: Single Technology and Commodity Perspective. *Energies,* Issue 8, pp. 12949-12974.

King, C., Maxwell, J. & Donovan, A., 2015. Comparing World Economic and Net Energy Metrics, Part 2: Total Economy Expenditure Perspective. *Energies,* Issue 8, pp. 12975-12996.

King, C. W. & Hall, A. S., 2011. Relating Financial and Energy Return on Investment. *Sustainability,* pp. 1810-1832.

King, C. W. & Hall, C. A., 2011. Relating Financial and Energy Return on Investment. *Sustainability,* Issue 3, pp. 1810-1832.

King, C. W., Maxwell, J. P. & Donovan, A., 2015. Comparing World Economic and Net Energy Metrics, Part 1: Single Technology and Commodity Perspective. *Energies,* Issue 8, pp. 12949 - 12974.

Lambert, J. G. et al., 2014. Energy, EROI and the quality of life. *Energy Policy,* Issue 64, pp. 153-176.

Lane, J.-E., 2016. *COP21 MANAGEMENT: Decentralised Policy-Making, International Governance and the Super Fund,* http://article.sapub.org/10.5923.j.env.20160602.02.html: Scientific and Academic Publishing.

Lenz, L., Munyehirwe, A., Peters, J. & Sievert, M., 2017. Does Large-Scale Infrastructure Investment Alleviate Poverty? Impacts of Rwanda's Electricity Access Roll-Out Program. *World Development,* Volume 89, pp. 88-110.

Mearns, E., 2013. *Energy Matters.* [Online]

Available at: http://euanmearns.com/energiewende-germany-uk-france-and-spain/

[Accessed 22 April 2017].

Mearns, E., 2015. *Energy Matters.* [Online]

Available at: http://euanmearns.com/china-post-industrial-revolution/

[Accessed 3 June 2017].

Mearns, E., 2016. *Energy Matters.* [Online]

Available at: http://euanmearns.com/primary-energy-in-the-european-union-and-usa-compared/

[Accessed 2 June 2017].

Mebratu, D., 1998. Sustainability and sustainable development: Historical and conceptual review. *Environmental Impact Assessment Review*, Issue 18, pp. 493-520.

Merril, T. L. & Miro, R., 1996. *Mexico: A country Study*, Washington: Library of Congress.

MMU, 2017. *MMU.* [Online]

Available at: http://www.business.mmu.ac.uk/seeg/whatis.php

[Accessed 28 February 2017].

Moore, H., 2015. Global Prosperity and Sustainable Development Goals. *Journal of International Development*, Volume 27, pp. 801-815.

Moran, D. D. et al., 2008. Measuring sustainable development - Nation by nation. *Ecological Economics*, Issue 64, pp. 470-474.

Murphy, D. J. & Hall, C. A., 2010. Year in review—EROI or energy return on (energy) invested. *Ecological Economics Reviews*, Issue 1185, pp. 102-118.

Murphy, D. J. & Hall, C. A. S., 2011. Energy return on investment, peak oil, and the end of economic growth. *Ecological Economics Reviews*, Issue 1219, pp. 52-72.

Nkomo, J., 2007. Energy use, poverty and development in the SADC. *Journal of Energy in Southern Africa*, 18(3), pp. 10-17.

NR Canada, 2017. *Natural Resources Canada.* [Online]

Available at: http://www.nrcan.gc.ca/energy/oil-sands/18078

[Accessed 1 June 2017].

Ozturk, I., 2010. A literature survey on energy–growth nexus. *Energy Policy*, Issue 38, pp. 340-349.

Poli, R., 2013. A Note on the Difference Between Complicated and Complex Social Systems. *Cadmus,* 2(1), pp. 142-147.

Ravallion, M., 2010. *Troubling Tradeoffs in the Human Development Index,* Washington DC: World Bank.

REN21, 2014. *First Decade: 2004-2014. 10 Years of Renewable Energy Progress,* Paris: REN21.

Stern, D., 2011. The role of energy in economic growth. *Ecological Economics Reviews,* pp. 26-51.

Trading Economics, 2017. *Trading Economics.* [Online]
Available at: https://tradingeconomics.com/russia/crude-oil-production
[Accessed 7 June 2017].

Tverberg, G., 2016. *Our Finite World.* [Online]
Available at: https://ourfiniteworld.com/2016/06/20/china-is-peak-coal-part-of-its-problem/
[Accessed 5 June 2017].

UCSASA, 2014. *Union of Concerned Scientists.* [Online]
Available at:
http://www.ucsusa.org/global_warming/science_and_impacts/science/each-countrys-share-of-co2.html#.WTq4ytwlG00
[Accessed 7 June 2017].

Unctad, 2017. *United Nations conference on Trade and Development.* [Online]
Available at: UnctadStat.unctad.org
[Accessed 26 July 2017].

UNDP, 2005. *Human Development Report,* New York: Hoechstetter Printing.

UNDP, 2015. *Human Development Report,* New York: UNDP.

UNDP, 2015. *UNDP.* [Online]
Available at: http://hdr.undp.org/sites/default/files/hdr14_technical_notes.pdf
[Accessed 22 January 2017].

Wells, J., 2014. Earth in the Anthropocene. In: *Complexity and Sustainability*. Oxon: Wiley, pp. 212-231.

Wolff, H., Chong, H. & Auffhammer, M., 2011. Classification, detection and consequences of data error: Evidence from the human development index. *The Economic Journal,* Issue 121, pp. 842-870.

World Atlas, 2016. *World Atlas.* [Online]
Available at: http://www.worldatlas.com/articles/the-top-10-coal-producers-worldwide.html
[Accessed 10 June 2017].
World Bank, 2016. *World Bank.* [Online]
Available at: http://databank.worldbank.org/data/home.aspx
[Accessed 4 June 2017].

Appendices

Appendix A: Price assumptions made for missing data

Table A1.1: Table showing the assumptions made for coal prices for the electricity sector (Source: King, et al. 2015)

Coal Prices - Electricity		
Country	**Time Series**	**Allocation**
Australia	1992-2010	USA electricity coal prices
Brazil	1978-1979 1980-1897; 1999 -2010	Data set minimum Mexico electricity coal price
Canada	1985-1989 1993-1999; 2010	Canada industrial coal price USA electricity coal price
China	1978-1979 1980-1991 1992-2004 2005-2009 2010	Data set minimum India electricity coal price China industrial coal price Chinese Taipei electricity coal price Dataset average
France	1978-1979	France industrial coal price
Germany	-	-
India	1978 2010	Dataset minimum Dataset average
Italy	1999-2002	Italy industrial coal price
Mexico	-	-
New Zealand	1978-1984 1985-1991 1992- 2010	New Zealand industrial coal price Australia electricity coal price USA electricity coal price
Russia	1978-1996; 2004-2010 1997-2003	Finland coal electricity price Russia coal electricity price
South Africa	2006-2010	Dataset minimum
Spain	1986-2010	Portugal electricity coal price
United Kingdom	-	-
United States	-	-

Table A1.2: Table showing the assumptions made for coal prices for the industrial sector (Source: King, et al. 2015)

Coal Prices - Industrial		
Country	**Time Series**	**Allocation**
Australia	1978-1981; 1990-1991 1992-2010	Australia electrical coal price UK industrial coal prices
Brazil	1978-1979 1980-1897; 1999 - 2010	Data set minimum Mexico electricity coal price
Canada	1990-1993; 2000-2009 1993-1999; 2010	Canada electricity price USA electricity coal price
China	1978-1979 1980-1991 2005-2009 2010	Data set minimum India electricity coal price Chinese Taipei electricity coal price Dataset average
France	2004-2010	France electricity coal price
Germany	1995-2010	Germany electricity coal prices
India	1991 1992 2010	Dataset average China industrial coal price Dataset average
Italy	-	-
Mexico	1978-1979 1980-2010	Dataset minimum Mexico electricity coal price
New Zealand	1985-1991 1992- 2010	Australia industrial coal price UK industrial coal price
Russia	1978-1995; 2004-2010	Finland electricity coal price
South Africa	1978-1979; 2002 2006-2010	South Africa electricity coal price Dataset minimum
Spain	1978-1985 1986-1996; 2004-2009 1997-2003; 2010	Spain electricity coal price Portugal electricity coal price Portugal industrial coal price
United Kingdom	-	-

United States	-	-

Table A1.3: Table showing the assumptions made for coal prices for the residential sector (Source: King, et al. 2015)

Coal Prices - Residential		
Country	**Time Series**	**Allocation**
Australia	1978-2010	Data set minimum
Brazil	1978-2010	Data set average
Canada	1978-2010	Data set average
China	1978-1991; 2003-2010	Data set average
France	2003-2005 2006-2010	Austria residential coal price Czech Republic coal price
Germany	1995-2005 2006-2010	Dataset average Czech Republic residential coal price
India	1978;1991;2004 2006-2010	Dataset average China residential coal price
Italy	1984-2005 2006-2010	Austria residential coal price Czech Republic residential coal price
Mexico	1978-2010	Dataset average
New Zealand	1978-1980 1985-2010	UK residential coal price Dataset average
Russia	1978-2010	Czech Republic residential coal price
South Africa	1978-1989 2006-2010	South Africa electricity coal price Dataset minimum
Spain	1978-2002 2003-2005 2006-2010	France residential coal price Austria residential coal price Czech Republic residential coal price
United Kingdom	-	-
United States	1978-2010	Dataset average

Table A1.4: Table showing the assumptions made for natural gas prices for the electricity sector (Source: King, et al. 2015)

Natural Gas Prices - Electricity		
Country	**Time Series**	**Allocation**
Australia	1978-1997 1998-1999; 2008-2010 2000-2007	Australia industrial natural gas price Canada industrial natural gas price Canada electricity natural gas price
Brazil	1978-2010	Data set average
Canada	1993-1999; 2008-2010	Canada industrial natural gas price
China	1980-1989 1990-2010	Data set average Chinese Taipei electricity natural gas price
France	1978-2010	France industrial natural gas price
Germany	2001-2010	Germany industrial natural gas price
India	1978;1991;2004 2006-2010	Dataset average China residential coal price
Italy	1978-2010	Dataset average
Mexico	-	-
New Zealand	1978-1984 1985-2010	Dataset average New Zealand industrial natural gas price
Russia	1978-1992; 1995-2000 1994; 2004-2010	Dataset minimum Russia industrial natural gas price
South Africa	1978-2001; 2003-2005 2002; 2006-2010	South Africa industrial natural gas price Dataset average industrial natural gas price
Spain	2001-2010	Spain industrial natural gas price
United Kingdom	1990-1992	UK industrial natural gas price
United States	-	-

Table A1.5: Table showing the assumptions made for natural prices for the industrial sector (Source: King, et al. 2015)

Natural Gas Prices - Industrial		
Country	**Time Series**	**Allocation**
Australia	1998-1999; 2008-2010 2000-2007	Canada industrial natural gas price Canada electricity natural gas price
Brazil	1978-1987 1999-2010	Dataset minimum Mexico electricity natural gas price
Canada	1993-1999; 2008-2010	Canada industrial natural gas price
China	1978-1989 1990-1996; 1998-2010	Data set average Chinese Taipei electricity natural gas price
France	-	-
Germany	-	-
India	1978-2010	Dataset average
Italy	1999-2003	Spain industrial natural gas price
Mexico	2008-2010	Mexico electricity natural gas price
New Zealand	1978-1984	Dataset average
Russia	1978-1992; 1995-2000	Dataset minimum
South Africa	2002; 2006-2010	Dataset average
Spain	-	-
United Kingdom	-	-
United States	-	-

Table A1.6: Table showing the assumptions made for natural gas prices for the residential sector (Source: King, et al. 2015)

Natural Gas Prices - Residential		
Country	**Time Series**	**Allocation**
Australia	1998-2010	Canada residential natural gas
Brazil	1978-2010	Data set average
Canada	-	-
China	1978-2010	Data set average
France	-	-
Germany	-	-
India	1978-2010	Dataset average
Italy	-	-
Mexico	1978-2003	USA residential natural gas price
New Zealand	1978-1984	Dataset average
Russia	1978-1992; 1995-1999; 2005-2010	Dataset minimum
South Africa	1978-2010	Dataset average
Spain	-	-
United Kingdom	-	-
United States	-	-

Oil

All countries were assumed the average annual Brent oil price for 1978 – 1979.

France oil prices from 1980-1991 were allocated German oil import prices.

All other prices given.

Table A1.7: Table showing the assumptions made for electricity for the industrial (Source: King, et al. 2015)

Electricity - Industrial		
Country	**Time Series**	**Allocation**
Australia	2005-2010	New Zealand industrial electricity prices
Brazil	1980-1987; 1992-20101	Data set average
Canada	-	-
China	1980-1989; 1997-2000 2001-2010	Canada electricity industrial price Russian industrial electricity price
France	-	-
Germany	-	-
India	1978-1987 1988-1991; 2001-2010	Canada electricity industrial price Indonesia industrial electricity price
Italy	-	-
Mexico	-	-
New Zealand	-	-
Russia	1980-2001	Canada electricity industrial price
South Africa	2007-2010	Dataset minimum
Spain	2001-2010	Spain industrial natural gas price
United Kingdom	-	-
United States	-	-

Table A1.8: Table showing the assumptions made for electricity price for the residential sector (Source: King, et al. 2015)

Electricity - Residential		
Country	**Time Series**	**Allocation**
Australia	2005-2010	Canada residential electricity price
Brazil	1978-1987; 1999-2010	Dataset average
Canada	-	-
China	1978-1994; 1998-2010	Canada residential electricity price
France	-	-
Germany	-	-
India	1978-1987; 2004; 2006-2010 1988-1991	Dataset average Indonesia residential electricity price
Italy	-	-
Mexico	-	-
New Zealand	-	-
Russia	1978-1992; 1995-2000	Canada residential electricity price
South Africa	2007-2010	Dataset average
Spain	2010	Portugal residential electricity price
United Kingdom	-	-
United States	-	-